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FAMILIAR LECTURES
ON
THE PHYSIOLOGY OF
FOOD AND DRINK

BY

ROBERT JAMES MANN, M.D., F.R.C.S.

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The Physiology of

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ROBERT JAMES MANN, M.D., F.R.C.S.,
Member of Council of the St. John's, Battersea, and Whiteland's, Training Colleges; and recently Superintendent of Education in the Colony of Natal.

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AUTHOR'S PREFACE.

THE Familiar Lectures contained in the following pages have been delivered at various times, and upon different occasions; some of them at the Training Colleges of St. John's, Battersea, and Whitelands, Chelsea, where intelligent and appreciative audiences for such kinds of teaching are always to be found. They are now arranged in a connected and consecutive order, and committed to print, in the hope that in this form they may have a still wider usefulness.

WANDSWORTH COMMON.
October, 1882.

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FAMILIAR LECTURES

ON THE

PHYSIOLOGY OF FOOD AND DRINK.

LECTURE I.

The Properties and Physiological Uses of Water.

Two thousand five hundred years ago, an eminent philosopher and teacher* held that water was the foundation of everything. He conceived that the earth was supported upon water, that heat was generated out of water, and that this so familiar liquid was, in reality, the origin of all material substance. It was a part of the conception in this old idea, that all animals live by water; or, in other words, that the primary food of animated nature is drink. In a certain sense, as will presently appear, this early inquirer made a very happy approach to a since physically-established truth; and he might, indeed, have extended his shrewd generalization further than he did, by including plants also within the scope of his remark. The notion, however, is so interesting, as well as important, in its ultimate results, that it is deserving of some further notice here, especially as it forms a convenient starting point for the line of

* Thales of Miletus, a city of Ionia, in Asia Minor.

thought, which it is proposed to pursue in the following lectures.

Few persons who have made any use of their faculties of observation will need to be told that plants cannot live without water. The green leaves of the trees and the fields obviously wither and die when the rain does not fall, and when the ground becomes parched and dry. But it is not every one who is aware of the full meaning of the difference when the rain does fall in abundance, and when the leaves are, in consequence, kept vigorous and green. The water first moistens the surface of the ground. It is then sucked into the loose porous soil, until it saturates this thoroughly to a considerable depth, and so, sooner or later, envelopes in copious moisture the fine rootlets of plants, which are branched out as little delicate threads, in its permeable substance.

These minute threads of the rootlets all end in small, thirsty mouths, which are called the spongioles of the roots, because they resemble little masses of soft sponge, and because they suck up water exactly as sponge would do. The imbibing ends of the roots are, it will be understood, not really open mouths. They are, compact hard-walled tubes, tipped at their extremities with soft, delicate cell substance, which is firm and close enough to prevent coarse substances, such as grains of sand, from intruding into the interior of the tubes, but which is not fine and close enough to exclude liquids that are as thin as water, from filtering through. The water soaks into the soft, spongy mass, just as it may be seen to do into porous blotting-paper, and so creeps on into the inner cavities of the tubes. This, therefore, is the first thing which happens when the rootlets of a living plant are duly supplied with water. The liquid passes slowly and gradually, but steadily and unceasingly, into the interior channels of the structure. The soft, porous spongioles of the roots are, as a matter of fact, only the young-forming tissue of the plants, which has not yet been hardened and rendered impervious to the passage of liquid by the full perfection of its growth. They are, on this account, often spoken of as the "growing points" of the roots. The young, tender points of roots are economically turned to account as mouths for the introduction of water.

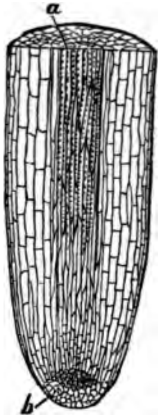

Fig. 1.—Section of the rootlet and spongiole of a plant, showing (a) the central duct, and (b) the soft terminal growing point.

When water is once fairly introduced into the interior of a plant, through the instrumentality of the absorbing spongioles of the roots, it finds itself in a connected series of tubes and cavities built up out of the matured, or maturing, vegetable textures. Some of these are constituted by the clustering together of little, thin-walled bladders. In such case the walls of the bladders are so delicate and fine, that the water filters through them, and creeps along from cavity to cavity with the utmost facility; the fine walled and permeable chambers are then technically spoken of as vesicles (little bladders), or as cells (little chambers).* The appearance which they present in the external part of a growing rootlet is shown in Fig. 1. In other instances the cavities, or chambers, are lengthened out, and fitted end to end, with either pits, or actual pores, impressed into the sides of the walls, to facilitate the passage of liquid from cavity to cavity. This is especially the case with plants that, like the vine, have a rapid growth, and a quick movement of the sap.

Very often the long-pitted chambers are fitted end to end with an open perforation passing from one cavity to the next, so that a free and altogether unimpeded flow of the liquid may take place, as through a lengthened out pipe, or tube.

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* From the Latin word *cella*, a chamber.

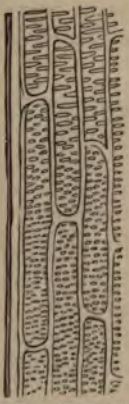

Fig. 2.—Pitted ducts of the stem of the vine.

The entire substance of a living plant is penetrated in this way by chambers and channels through which liquid can flow, and these channels extend from the lowest spongioles in the ground to the highest leaves stretched out into the air. The leaves themselves, indeed, are but a continuation of the same kind of structure. They are made of layers of cells packed end to end, and layer above layer, like the bricks in a wall. But the cells of the leaf have hollow interiors, and thin walls of permeable membrane, so that liquid may glide and flow from cavity to cavity.

In some exceptional instances these chambers and tubes of plant substance can be readily discerned by the naked eye. But more generally they are so small that it requires the skilful use of the microscope to make them out, as they are shown in drawings. The representations of such structure given in books are almost always taken from portions of the plant which, after due preparation, have been examined by the microscope with high magnifying powers. All the ingenious and elaborate contrivance so brought to view is, nevertheless, actually employed, in order that water may have a ready passage everywhere through the interior of a plant, as long as it is a living structure.

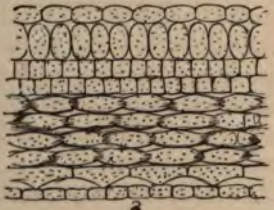

Fig. 3.—Magnified section of the leaf of a balsam, showing the arrangement of the vesicles, or cells.

But the next question that presents itself for consideration, is the natural one, of what ultimately becomes of the water which thus enters so abundantly into the plant. This it is very easy to answer. The greater part of it escapes out of the leaves in the form of invisible vapour. If a clear, bell-shaped glass is covered over a vigorously growing plant, standing out in the sunshine, it very soon becomes dripping inside with moisture. This is all water, which has evaporated out of the leaves of the plant, and then been condensed upon the inner surface of the glass. The quantity of water that is thrown out in this way by living plants, has, in many instances, been carefully measured. A large sunflower gives off from its leaves, as much as thirty ounces, or one pint and a half, every twenty-four hours. An acre of grass land pours out as much as 6400 quarts in the same interval of time. This, however, only takes place in sunshine, or daylight. In the darkness of night, the evaporation from the leaves altogether, or nearly, stops. The action is therefore one of pumping by sunshine. When the sun shines upon the leaves, they pump up water from the moist ground under the stimulus of some force which the sunshine sets going. There is, indeed, a special provision made in the structure of the leaves, to enable this sun-pumping action to be carried on.

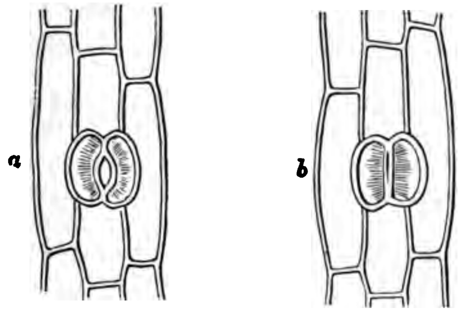

Fig. 4.—Stomate of the epidermis of the leaf, showing the pores open at *a*, and closed at *b*.

The thin walled cells of the leaf, which have been described as packed together, layer above layer, to form the

The water looks almost as clear, after it has united with them, as it was before they were mingled with it. It is also quite as mobile in its nature when in combination with them as it is when pure and free from them. Both syrup and brine flow much in the same way as water. The water, 3 then, which enters the spongioles of the roots, carries with it a very considerable, although unseen, load of solid food. But the water, which escapes as vapour from the transpiring pores of the leaf, is very pure water. What therefore has become of the burthen which was carried by it into the plant? It is left there, in the store-chambers of the interior, and is used as material for building up purposes.

This, then, is what modern science means when it extends the doctrine of the old sage of Miletus so far as to say that plants live by water. They live by water, because water in its ready flow carries in through the quite invisible pores of their structure vast loads of food-substance which could not be introduced into the small chambers of that structure by any less refined and less subtle method of transport. It will hereafter be seen, that water is also itself a part of the food which is used in building up structure, as well as an agent of transport. The whole of the water which enters a plant by the absorbing spongioles of the roots, does not escape into the air through the transpiring pores of the leaves. Some part of it is retained as a contribution to building purposes. The little molecules of this retained water are loosened asunder into their elementary constituents, and these are mingled in with the other raw material that is appropriated to the processes of construction. It is probable that the same flower which exhales a pint and a half of water from its leaves in twenty-four hours, drinks in something more than two pints by its roots within the same period. The balance, which remains when the pint and a half has been dissipated by the leaves, is the portion of water that is turned to account as actual food. It may, therefore, be truly said, in a double sense, that plants live upon water. But the larger truth, which it is the more immediate object to enforce here, still remains—namely, that water is the carrier in chief in the economy of Nature.

The several specific properties of this most familiar substance, water, are not only interesting, but, in some measure, marvellous, when considered in connection with the services which are performed. In the first place, there is its singular and irrepressible mobility. Water is always in motion. It floats up to the clouds as vapour; it falls from the clouds as rain; it runs along the slopes of the ground as streamlets and rivers; it rises up as waves, and it rolls over as billows. This ready mobility is due to the fact that it is made up of little round balls or spherules, which have no firm adhesion to each other, but roll over and over, this way and that, under any impulse that is communicated to them. The spherules are very minute. They are much too small, indeed, to be individually seen, even with the help of powerful microscopes. But they have, nevertheless, a very real existence. When a lump of frozen water, or ice, is laid upon the ground, it remains still in the place in which it is put, because the numerous molecules of the substance are then attached rigidly together by the agglutinating power of frost. If, however, such a lump of ice be thawed by the sunshine, it no longer rests in its place, but streams away in the form of dribblings of water. The thawed water is drawn down to the ground in the same way as the lumps of ice—that is, it is attracted by, or gravitates to, the earth. But as soon as its top molecules are loosened from the immediate neighbours to which they were previously bound by the frost, they obey the earth's pull, and roll over like little balls until they reach the ground, and still go on rolling lower and lower, along the slope of the ground, until they get as low down as they can towards the middle of the earth, which is the main centre of the attraction. It is the weight of the water, or its gravitation towards the centre of the earth, and the inability of the constituent molecules to hold firmly together under the disturbing effect of the earth's pull, which together combine to render the liquid substance fluent or flowing, whenever it is not confined in some vessel. When a jug containing water is sufficiently inclined for the liquid to pass over the restraining rim, the water does not tumble out of the jug to the ground in a lump, but it flows out in a stream, the little molecules rolling and gliding over each other in a never-ceasing change of relative position. That is what is meant by the running of water. It is not possible to conceive any contrivance more suitable for the purpose of transport than this plan of making the whole substance, as it were, a congeries of wheels, free to roll forward under the slightest impulse, and of then supplying this impulse from the attraction of the earth, wherever the slope of the ground lies in a downward direction. It is true that, in accomplishing its task of carrying food-substance into the interior of plants, water has to flow up instead of down, after it has once come into close contact with the spongioles of the roots. But there is a secondary reason for this, which will presently be made apparent.

The power which water possesses of dissolving various kinds of solid material into a close intercommingling with its own substance, by loosening the mutual adhesion of the little molecules, and then scattering them freely amongst its mobile parts, and in that way rendering them, for the time, as fluent as itself, is another peculiarity by which it is eminently fitted for its work of carrying. This power of solution, is not, however, indispensable to its accomplishing that task. Water does not dissolve every kind of body that is immersed in it. If a bullet or a stone is put into water, neither of them would be dissolved in it after any lapse of time. Yet running water, in a way, moves stones which it does not dissolve. It does so by pushing them along, as it strikes a number of its own little molecules against them, and by, in some measure, buoying them up, and rendering them, in that sense, less heavy to move. Sand-grains are simply very small stones, and everybody knows that they are hurried along in the currents of rivers. But, as a matter of fact, insoluble bodies are not as readily transported by water as bodies that have been broken up into their smaller parts. Sand-grains are more easily carried than large stones, and so, in a similar way, the entirely separated molecules of soluble bodies, which are very much smaller than sand-grains, are more easily carried than those grains. And then, again, insoluble particles, like sand, cannot be introduced into the interior cavities and chambers of growing plants, which are guarded from the intrusion of such coarse material by the delicate webs and membranes of which they are composed. But dissolved bodies can be carried up and through the invisible, and otherwise quite undiscoverable, pores of these membranes, as readily as pure water itself. Hence it is that soluble substances are used for the nourishment of the textures of growing plants. Whatever is required to be turned to account for that purpose is first, by a convenient and subtle process of chemistry, converted into some state in which it can be dissolved by water. The greater part of those innumerable bodies termed salts, such as the well-known compounds of potash and soda, are substances which have been brought into a soluble condition by chemical agency, in order that they may be amenable to the dissolving powers of water.

A third, important, and very notable property of water, when considered in reference to the part it has to play in the business of nature, is expressed in the circumstance that it does not itself, for the most part, exert any decomposing or destructive influence upon the bodies which it dissolves. It carries whatever burdens are entrusted to it for transport with irreproachable honesty, giving them all up, at the end of its trust, exactly as they were received. If an ounce of salt or of sugar be dissolved in half a pint of water, the solid mass disappears to the eye, because its minute molecules are scattered loosely in the water. But that those molecules, although they cannot be seen, are really there, and unchanged in their essential qualities, becomes at once obvious if the liquid is touched by the tongue. Either the salt or the sugar, as it may be, is then tasted, and consequently known to be present in the water. If the solution be afterwards placed in an earthenware jar, and stood upon the hot plate of a stove, the water will gradually be driven away as vapour, but it will not take a single grain of either the salt or the sugar with it in its flight. In the end, the ounce of salt or of sugar will be found left behind in a solid state in the vessel, and to be recovered exactly as it was before it was put into the water. A very brief consideration will suffice to make apparent how valuable this incorruptible honesty of water must be in view of its function as a carrier of building material for the constructive operations of plants. It takes into their chambers such things as are required for the particular work on hand. But this would be of small avail for the ultimate result, if those required substances were tampered with and destroyed by the way. The chemical impassiveness and indifference of water is as important to its work as its ready mobility.

But although water is thus indifferent and honest, it very materially favours the action of bodies that do chemically interfere with one another when these are put together in a state of solution; because, in this state, the loosened out molecules of each are very readily brought into close contact. In the freely mobile and fluent condition to which they are reduced by this instrumentality, they easily find each other out and run into intimate connection. If an ounce of carbonate of soda and an ounce of tartaric acid, in a state of powder, be mixed together in a mortar and kept in a dry place, they do not in any way interfere with one another; the grains of carbonate of soda lie side by side with the grains of tartaric acid. But if the mixed powders be thrown into a glass of water, the soda and tartaric acid, being soluble substances, are both dissolved, and they then immediately attack and, so far as their chemical condition is concerned, destroy each other. The water is thrown into vigorous commotion, bubbles of carbonic acid, set free by the destructive decomposition of the carbonate, escape, and there then remains in the water neither carbonate of soda nor tartaric acid, but a new and quite different kind of substance, called tartrate of soda, which has been formed by the mingling together, in intimate chemical union, of the soda and the acid. If the solution be placed in an earthenware saucer standing upon a hot plate, when all the water has been evaporated and driven away by the heat, there remains, not an ounce of carbonate of soda and an ounce of tartaric acid, but a quantity of tartrate of soda; and this quantity is less than two ounces by the exact weight of the carbonic acid which has escaped into the air during the effervescence. The importance of this influence of solution is that it favours the conversion of the dissolved body into the material of structure, after it has been washed into the interior cavities of plants. It is there, in its loosely distributed and dissolved state, intimately mingled with other ingredients, so that their influences upon it can be brought into play to determine the building up of the whole into consolidated textures.

The ability of water to be turned into thin vapour by heat, and of the vapour to be again recondensed into water, when the heat is withdrawn, is another property which is altogether indispensable for the work this willing servant performs. Water is nearly eight hundred times denser than air, because the little molecules, of which it is composed, lie so much more closely together. This it is which makes a pint of water so much heavier than a pint of air. But when water is heated to 212° of the artificial heat-scale of Fahrenheit—or, in other words, to the boiling point—it is suddenly turned into a vaporous state, in which it is somewhat more than as thin again as air. A cubic inch of water acquires the bulk of a cubic foot when it is converted into steam—that is, it occupies nearly 1,800 times as much space as it did in the liquid state. But in this thin, vaporous condition it is at all times escaping from moist or wet spaces on the earth, in more or less copious quantity—in larger quantity when the surrounding temperature is high, and in less when the temperature is lower; but in some quantity, whatever may be the state regarding heat. Portions of the liquid molecules are elastically tossed off from the surface of the water, and then float away into the intervals separating the particles of the air; and, in doing so, become imperceptible to the eye, because each separate molecule, when taken apart, is so surpassingly minute. Air, at the temperature of ice, can contain nearly two and a half grains of aqueous vapour in each cubic foot, distributed through it in this approximately impalpable and quite imperceptible way. In the temperature of a warm summer day it can, on the other hand, contain as much as eleven grains in each cubic foot. It may in general terms be assumed that, upon the average, there is rarely less than a pint and a half of water in every hundred pints of air. But, in consequence of the different capacity of hot and cold air to sustain the invisible charge of vapour, it follows that whenever the air of a warm summer day, containing its full burthen of invisible vapour, is chilled nearly down to the temperature of frost, something like nine grains of water are thrown down out of every cubic foot of air. This, then, is the secret spring of the mechanism of rain.

Aqueous vapour floats up in greater or less abundance from the rivers, and seas, and from moist ground, and in the high and chill regions of the air, is condensed, first into fleecy, rolling clouds, and finally into copious showers. The water deposited as showers upon the ground then runs down the hill-sides, and gathers into the still descending channels of the rivers, finally reaching the lower basins of the sea; and in this way the circle is complete. By the evaporation of water from the basins of the sea, and from the moist places of the earth, the clouds and the rain are perennially fed; and by the streaming down of the rain along the inclined slopes and channels of the ground, the liquid evaporated from the widely-spread basins of the sea is in the end restored to those vast natural reservoirs. But it is the sun's heat and the attraction of the earth for the gravitating liquid, which are the moving forces of this circling play; the powers that work the subtle mechanism. In this marvellous way the restless carrier of the burthens of nature is nerved for its arduous work, by the mere antagonism and alternating predominance of sunshine and gravity.

But the raw materials provided for the building operations of plants have to be carried *up* after they have been brought to the absorbing spongioles of the roots. In the case of a lofty, yet still-growing tree, they may have to be lifted even hundreds of feet high. This, of course, cannot be accomplished by the *downward* flow of water under the influence of gravitation. A supplementary agency is therefore brought into play. In what way this is managed may, perhaps, be most easily understood by reference to the simplest form in which the action can be exhibited. If a bladder be filled with thick syrup, and then tightly tied up round the neck, it may be made to sink in a tub of water by fastening it to a weight. Now, when such an arrangement has been carried out, and the bladder of syrup is left in the water, it soon begins to swell itself out, and to grow very tense. This is because thick syrup draws water in to itself through the pores of any permeable membrane, such as bladder is. If the conditions of the experiment were so far changed that a bladder of water was immersed in thick syrup, exactly the opposite kind of transference would occur. The bladder would grow flaccid and loose, because much of the water would be *taken out* from it, through the membrane, to mix with the syrup. Currents of water are therefore established in this way in both cases. In the one the water flows in to the interior of the bladder, and in the other it flows out; and the force with which this is accomplished is strong enough to sustain the flow, even when it is in an upward direction against the influence exerted by gravity, or, in other words, by the weight of the water. Now, to a growing plant, all the upper portions of the structure, such as the leaves, have the juices of that part thickened by the influence of evaporation. Thin water escapes through the exhaling pores, leaving behind a thicker liquid which holds the various soluble ingredients dissolved. But the thick, syrup-like sap above, being only separated from the cells of the stem and roots below by a series of thin, membranous partitions—the walls of the numerous vesicles and cells—the thin water from below is immediately drawn up to mix with the thick, syrup-like liquid above, and this operation extends downwards step by step, each cell above drawing in water from the one below, until at length it reaches the actual extremities of the roots, when the thicker sap within the cavities of the spongioles draws in liquid out of the surrounding moist soil. It is in this simple way that the rise of the food-containing liquid into the higher parts of the plant, where that food can be turned to account, is managed. The process of the passage of a thin liquid through a porous membrane to mingle itself with a thicker one, is technically, and in the language of the physiologists, distinguished as "Endosmose,"—inward drawing or impulse.* In strict reality, there is always a double flow, a transference of some of the thin liquid towards the thick, and of some of the thick towards the thin. But the balance is always in favour of an accumulation towards the thick. More passes inwards than outwards. The effect of this movement by endosmose is shown very prettily by a simple experiment which any one may easily make. A tube of glass, about half an inch in diameter, is closed at the lower end by tying a covering of thin bladder over it, and thick syrup is poured in until it stands about three inches deep. That end is then plunged into a glass of pure water, and very soon it is observed that the water is drawn in through the bladder to mix with the syrup, and that this consequently rises up in the tube, from the increase of its bulk caused by the dilution with water, until it is several, instead of three, inches deep.

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* From the Greek words *endon*, within, and *osmos*, impulsion.

LECTURE II.

The Elaboration of Food-Principles by Plants.

ALTHOUGH water is the great carrier of nature, it is not able to accomplish all the work of this character which is required, for the simple reason that all the raw materials, which are needed for the building operations of plants, are not soluble in water. There is charcoal, or carbon, as it is also called, for instance, which is largely used in the consolidation of the textures of plants, and must therefore be introduced into growing plants in considerable quantity. If a piece of white paper, which is primarily made out of vegetable tissue, be burned in the flame of a candle, there remains a thin black ash in the place of the white paper. That black film is almost entirely charcoal. Every observer is aware of the charred lump which is left behind when dry wood is half burned. That, too, is the black charcoal, or carbon, which was originally carried into the interior of some growing plant, when the wood was in the process of construction. But if a lump of this dense, black substance be put into water, it will remain there any length of time unchanged. It cannot be dissolved in water.

An altogether different agent consequently undertakes to deal, in the first instance, with this refractory body which water alone cannot manage to convey. The result, however, in the end, is accomplished in a not very different fashion. The solid is broken up into loosened molecules, and is in that sense dissolved. But it is dissolved into a thin, invisible vapour, or, as it is termed, gas, instead of being first loosened out into a liquid and still visible condition, as water and water-dissolved bodies are, and this vapour is then found to be soluble in water. The agent of the solution is one of the natural constituents of the air, that elementary ingredient which is known as "oxygen." When a piece of black charcoal is heated to redness in the presence of air, and then blown upon by a stream, or current, of air, it burns away and disappears. But that burning is substantially a solution of the black solid in one of the constituents of the air. A single molecule of the black solid is seized upon by two elementary molecules of the cxygen, which constitutes a fifth part of the bulk of the air. The three molecules combined into this ternate group then become a compound molecule of another vapour-like substance, which is termed carbonic acid gas.

Symbol expressing the chemical composition of each molecule of carbonic acid, CO^2.*

It is the heavy, although air-like vapour which escapes out of all fermenting liquids, and which causes the effervescence when carbonate of soda is mingled in solution with tartaric acid.†

Carbonic acid is an invisible vapour, or gas, because its molecules are too minute to be individually seen, and because those molecules are scattered very widely asunder after the manner of a vapour, or gas. In a pint bottle, full of carbonic acid gas, which would not weigh more than sixteen grains, or about half as much again as a pint of air, there would be not quite seven grains of carbon. In other words, seven grains of black charcoal are enough, with the help of a due quantity of oxygen, to make a full pint of carbonic acid gas. The seven grains, in being converted into carbonic acid gas, are thus spread out through this bulk. Each compound molecule is held floating far apart from its neighbours;—so far that the whole of them cease to be visible. Each one is invisible because of its exceeding minuteness, and no two are near enough to be seen as if they were one. This power of the oxygen gas constituent of the air, to render dense and refractory carbon both vapour like, and, as vapour, soluble in water, is, in view of the remarkable results to which it leads, a noteworthy circumstance.

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* In the symbols expressing chemical composition, the letters represent the initial capitals of the elements, as C for carbon, and O for oxygen, and the figures the number of the atoms of the elements with which the figure is associated. Thus, CO^2 means that each molecule contains one atom of carbon, and two atoms of oxygen.

† See page 21.

One consequence of this relation of atmospheric oxygen to dense carbon, is that there is always a considerable quantity of vapour-like carbonic acid floating in the air. It is poured out into the air wherever combustible substances, containing carbon, are in the process of burning; but the decay of dead organized structures, and even the breathing of animal bodies, is a slow kind of burning. From these sources also, there is, therefore a copious supply. At all times as much as one pint of carbonic acid is found in every 2860 pints of air; or something like sixteen grains of carbonic acid to each four pounds of air. This seems to be in itself but a trifling quantity; but it is really a vast amount when large spaces of the air are concerned. In consequence of the great height of the atmosphere, there are something like 1,300,000 tons of carbonic acid resting upon every square mile of ground. That would give something more than 370,000 tons of charcoal held up in the air, by the buoyant force of oxygen, over each square mile. There can, therefore, be no lack anywhere of this particular ingredient for the needs of plants. The trees, shrubs, grasses and weeds, that grow upon any square mile of ground, can get out of the air, which rests above them, not less than 370,000 tons of carbon for the timber and other solid textures they are building up within their interior chambers; and even more than this in the end, because this quantity is maintained in the air as portions of it are being withdrawn. As fast as the carbonic acid is taken out of the air by living plants, it is being poured back into it by the breathing of animals, the burning of fires, and the destructive decay of all kinds of carbonaceous compounds. A single pair of human lungs gives out into the air a cubic inch and a quarter of carbonic acid gas, and therefore half a grain of carbon, with each breath. In the course of a single hour this amounts to 1296 cubic inches of carbonic acid, or to 586 grains of carbon. It will readily be conceived, therefore, how enormously vast must be the supply from the 1456 millions of human beings, and the still larger number of other kinds of breathing animals, which dwell upon the earth.

The carbonic acid gas, which floats in the interspaces that lie between the molecules of the air, being soluble in water, is carried in considerable quantities down to the ground whenever rain falls. It is washed out of the air into the ground, and is then sucked in with the other soluble matters through the spongioles of vegetable roots. But more than this. As it drifts lightly along in the air it strikes continually against the leaves of plants; those leaves, which, it will be remembered, are sprinkled over with quite uncountable numbers of open mouths, or pores, and, as soon as it has done so, is mingled with the vegetable juices contained in the cells, and exposed with them to the influence of daylight and sunshine. By this means the solid ingredient, the black carbon, is brought back out of the grasp of the oxygen, and left available to be built in as the great consolidating principle of vegetable structures.

with the other substances transported by water into the leaf. The green colour of the leaf itself is a part of the vegetable fabric which is in this way constructed by the help of carbon. But, as the carbon, which is thus fixed, is withdrawn from the grasp of the oxygen, that gas is left free, and has to be expelled from the leaf. This is accomplished by the same open route. It passes out through the pores of the leaves. If a few green leaves are immersed in a dish of water containing carbonic acid, and are left standing in the sunshine, this interesting process of vegetable elaboration may be watched in actual progress. A vast number of bubbles soon gather about the under surfaces of the leaves, which can all be shown to be bubbles of pure oxygen gas. Carbonic acid is taken in from the water through the pores of the leaves, and, by the instrumentality of the force derived from the sunshine, the oxygen and carbon contained in the carbonic acid molecules are torn asunder, the carbon being retained to be built into the structures of the plant, and the oxygen being ejected through the same leaf-pores as agents which have accomplished their task, and whose presence, therefore, is no longer required.

Carbonic acid gas is one of the most important of the food-substances appropriated by living and growing plants, because the load of ponderous carbon is introduced by its means into all consolidating tissues. It is the great source of solidification and density by which rigid form is secured. The various ingredients, which are brought together in the work of vegetable fabrication, are made plastic and firm by the mingling in with their molecules of a due quantity of this solid base. As water is the great agent of mobility and transport, carbonic acid is the chief source of durability and fixedness. In consequence of the great abundance of dense carbon its fibres contain, the heart-wood which has been built up in the stems of large trees remains unchanged for centuries. In the vast deposits of coal which lie buried in the earth, charcoal, originally deposited in living plants as wood, has remained unaltered in all probability for many thousands of years. This fixed durability of charcoal is due to the circumstance that, once it is amassed in the solid state, it is as indifferent to the chemical solicitations and seductions of all other elements, as it is to the dissolving influence of water. Oxygen gas is the only exception to this habit of self-contained indifference, and even oxygen has no power over its ponderous and indolent molecules at ordinary temperatures. It is only when they have been raised to a red heat by the operation of fire that the charm is dissolved, and the black molecules are loosened out from their mutual coherence, and given over to the grasp of the then irresistible oxygen. But when carbonic acid has once been formed out of carbon and oxygen by the agency of heat, it, in its turn, acquires in some degree the same stubborn resistance to change which is characteristic of the solid constituent it contains. No artificial influence that the skill of the chemist is capable of bringing into play, can wrest back the solid carbon from its association with oxygen. The resolution and reconversion of carbonic acid gas into its primary elements is a task that is reserved for the supreme agency of sunshine, co-operating with the subtle energy of vegetable life; great natural forces which transcend the efforts of artificial interference. This is a noteworthy feature, it will be observed, in the vital operations of plants.

The narrative of the marvellous provisions that have been made for the work of organization, and for the maintenance of vegetable and animal life, cannot be held to have been intelligibly told, or to have been rendered fairly complete for the purpose contemplated in these lectures, until some other conditions and circumstances associated with those which have been already explained, have also been brought under notice.

In the first place, it must be understood, that the great agent of transport, water, is itself not a simple substance. It is constructed by the instrumentality of two distinct ingredients, which are each and both, in their separate individualities, vapours or gases. If a few shreds of zinc and a little sulphuric acid be placed in a bottle half full of water, and a narrow glass tube be then fixed in the mouth of the bottle, bubbles of gas will very soon rise in the water and escape in a stream from the tube. This stream of gas can be then set light to as it escapes, and may be seen burning as a pale flame. The gas procured in this way is very light as well as inflammable. It is the one, indeed, which is used on account of its levity for the inflation of balloons, and it is called hydrogen, or the generator of water, in consequence of the part which it plays in the construction of that liquid. It is really formed in the process just described by the destruction, or taking to pieces, of a portion of the water. If a cold drinking glass be held whelmed over the burning flame, water soon appears trickling down inside of it. This water is again derived from the hydrogen during the process of burning. As it burns it is united with the oxygen of the air, very much as carbon is when it is made red hot and dissolved into carbonic acid. Two atoms of the light hydrogen and one atom of the oxygen combine together to form a molecule of water.

Symbol expressing the composition of each molecule of water,

$H^2 O$.

Unlike, however, to carbonic acid, water can be both formed out of its elementary constituents, and unmade by the artificial operations of the chemist. This is shown in the experiments just alluded to, where the water is decomposed and broken up into its ultimate elements by the action of sulphuric acid and zinc; and where water is formed by combining the hydrogen burning in the flame with oxygen procured from the surrounding air.

The oxygen gas, which is furnished to the burning hydrogen from the air, and supplied, it will be remembered, to red hot and burning charcoal in a similar way, is not present in the air merely as an accidental visitor. It is, as all fairly intelligent people now know, itself an essential part of the air, which consists of two ingredients, loosely mingled together; that is to say, the particles of the two float freely amongst each other, without ever coming into actual contact. The oxygen-particles have no more power, at ordinary temperatures, of interfering with the particles of the companion they are associated with, than they have with the black, cold mass of solid charcoal. They accordingly remain in quiet and unaggressive companionship with this associate, and in that unaggressive and passive companionship constitute the air.

But the companion or ally, which is associated with oxygen in the air, is also a thin vapour, or gas. It is the gaseous substance distinguished by scientific men as "Nitrogen." This name was given to it, in the first instance, because it had been ascertained, at a very early period of chemical observation, that it contributes supplies of its molecules to make the white salt, familiarly known as nitre. The word nitrogen merely means the generator of nitre. The air then is essentially a mingling together of oxygen and nitrogen gases in the proportion of twenty-one volumes of oxygen to seventy-nine volumes of nitrogen. There are two atomic or elementary particles of the nitrogen to each single particle of the oxygen. But they are all suspended free from each other, and relatively far apart; that is, with blank intervals between them, which are many times wider than the particles themselves are broad. Each gas, in the circumstances of this arrangement, behaves itself exactly as it would if there were no second kind associated in near neighbourhood with it. It drifts freely about in the intervals that lie between the particles of its associate and neighbour.

But the two gases, which thus constitute air by their commingling, are of a very different character. The one, full of restless activity and energy, is prone to attach itself intrusively to most other kinds of molecules that come within its reach; the other, self-contained and reserved, is disinclined to contract structural alliances with any other kinds of atoms. Oxygen gas attacks pretty well all kinds of material substance, as it attacks burning charcoal and hydrogen, being, indeed, the great agent of chemical transformation. It is, on the whole, the most important and energetic of the sixty-six distinct kinds of bodies or elements, of which material nature consists. It is so abundant that by itself it apparently makes up quite one half of the substance of the ponderous earth. In the body of a man, which weighs perchance something like 154 pounds, 109 pounds of the weight are made up of oxygen alone. Not less than 1290 cubic feet of gaseous oxygen are condensed into the structures of a full-sized human frame. Nitrogen gas, on the other hand, although so plentiful in the air, where its indolent and indifferent temperament has free scope, is comparatively rare in the more substantial portions of the earth. It enters in any considerable amount into the composition of only the most elaborate and finished products of living organization, when, in the interest of such products, its inertness has been for a time overruled by the higher force which is inherent in the action of vegetable life. The human body, which contains as much as 109 pounds of oxygen, has not more than four pounds and a half, or sixty-six cubic feet, of nitrogen in its structures. Nitrogen is so inert in its chemical proclivities, that it cannot be forced into combination with other elements by artificial or human agency. It needs for that purpose to have the same subtle powers brought to bear upon it that are used for the resolution of carbonic acid, the stimulus of the sunshine, and the co-operation of vegetable life; and even with these it has to be taken advantage of in a weak and unguarded moment,* before it can be so turned to account. It is almost certain that the nitrogen of the air, abundant as it is, is scarcely, if at all, employed in constructive work. The considerable amount which is drawn upon by building plants is derived from a quite different source.

The vast quantity of nitrogen which exists free in the air, serves, in the main, as a foil and restraint to its more versatile and restless associate. It moderates and subdues the aggressive impulses of the oxygen. In the atmospheric alliance, the oxygen is the active, and the nitrogen the passive, member of the partnership. The oxygen is in a constant process of withdrawal and return in relation to the great free aerial store. The nitrogen in it, on the other hand, is a comparatively fixed and unchanging ingredient. The main bulk of the oxygen of the earth is held tightly grasped in the liquid and solid portions of the terrestrial mass, and only a small superfluity is left to roam free as a floating gas, or air. But the main bulk of the nitrogen drifts free and uncombined in the air. The predominant characteristic of oxygen is the tendency to seize upon and compound itself with other elementary bodies. The predominant characteristic of nitrogen is its ineradicable habit of maintaining its own separate individuality and independence, and of spontaneously resuming that independence as speedily as possible when it has been temporarily constrained to submit to interference. The combining habits of oxygen are prominently manifested in the corrosions which it so abundantly produces. The solitary and separative habits of nitrogen are no less strikingly exhibited in the readiness with which nitrogen-containing organic substances undergo putrefaction and decay, and resolve themselves into their constituent elements. Both oxygen and nitrogen, therefore, contribute, although in a different way, to the destruction of complex bodies that have been built up by the constructive energies of plants. Oxygen sets the destructive process going by the eager energy with which it attacks chemical combinations that have been already formed. Nitrogen favours and forwards the process by the facility with which it slips away from the complex clusterings of atoms that have been built into organized fabrics.

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* It must be in what is termed the "nascent state," that is, freshly set free from chemical combinations with other elements.

But when nitrogen separates itself from complex combinations in which it has been temporarily involved in organized structure, it clings to one of its associates a little more than it does to the rest, and in that state constitutes the pungent vapour, or compound gas, which is known as ammonia. When organic bodies, which have included nitrogen amongst their constituents, decay or decompose, the pungent smell of ammonia always presents itself. This ammonia is composed by the lingering of nitrogen in union with hydrogen gas. Three atoms of the light hydrogen attach themselves to one atom of nitrogen.

Symbol expressing the composition of each molecule of ammonia H^3N.

But ammoniacal gas thus formed is soluble in water, as inert nitrogen itself is not. Hydrogen, light as it is, has thus, in certain circumstances, the power of accomplishing for nitrogen very much the same service that oxygen performs for carbon. It overcomes the habit of self-contained isolation, and brings it back within the sphere of elaboration and reconstruction from which it was just on the point of escape. Ammoniacal gas is, then, the source from which nitrogen is procured when it serves as one of the food-principles of plants. It is so soluble in water, that this liquid, which can only hold in solution about its own volume of carbonic acid, can take up not less than 670 times its volume of ammonia; that is, one pint of water can condense into itself and hold 670 pints of the pungent vapour.

The liquid known as spirit of hartshorn is nothing but the soluble gas, ammonia, dissolved in a very large quantity in water. Its penetrating smell is the volatile gas, as it slowly escapes back from the water, making its impression upon the membranes of the nose. This compound vapour was called ammonia in the early days of chemical observation, because it was, in the first instance, noticed exhaling spontaneously from a white salt scattered upon the ground in the neighbourhood of an old heathen temple in Libya, consecrated to the worship of Jupiter Ammon. It was then looked upon as sal ammoniac, or the ammoniacal salt. Whenever sal ammoniac is broken up and mixed with a little quicklime, ammoniacal gas pours off from it in overwhelming and suffocating abundance.

This compound and pungent gas, ammonia, is present at all times, in small quantities, with the carbonic acid gas that floats in the interspaces separating the molecules of the air. There is not, however, so much of it at any one time in the air as there is of the carbonic acid gas. Ordinarily, there is not more than one pint of gaseous ammonia in 100,000 pints of air. This is, in reality, a consequence of the very great and ready solubility of the gas. It is always being poured out into the air from decomposing organic substances. But it is washed out of the air by the rain almost as rapidly as it is supplied, and so carried down to the soil. About thirty pounds' weight is conveyed by the rain to every acre of ground each year. Therefore the plants growing in the ground can get an ample supply of nitrogen for the building up of their structures, although ammonia is retained in such limited proportions in the air. As, however, in its free state it is of so irritating and pungent a character, it is first converted in the ground into unpungent, neutral, and yet soluble salts, and is then, in that state, carried in through the spongioles of the roots with the other substances that are held dissolved in the upflowing water. It is worthy of note that although ammon cannot be formed by the artificial processes of the chemists, it can be quite easily resolved by human agency into its constituent elements. If a quantity of pure gaseous ammonia be closed up in a porcelain tube, and the tube be then strongly heated, no pungent gas will be found in the interior of the tube when it is again opened. All the volatile smell will have disappeared, and there will be discovered in the tube only a mixture of hydrogen and nitrogen gases, associated together in a kind of loose intermingling. One-fourth of the resulting mixture can then be shown to be nitrogen and three-fourths hydrogen.

The principal food-substances of plants are thus the three notable compounds which have just been described, namely, carbonic acid, water, and ammonia; and these, it will be observed, are all formed by the union in pairs of some of the four primary elements that have been also specified and described, namely, the gases oxygen, nitrogen, and hydrogen, and the solid element, carbon. The relation of these three important binary compounds to the elements of which they are composed may be advantageously presented to the eye in a diagramatic form.

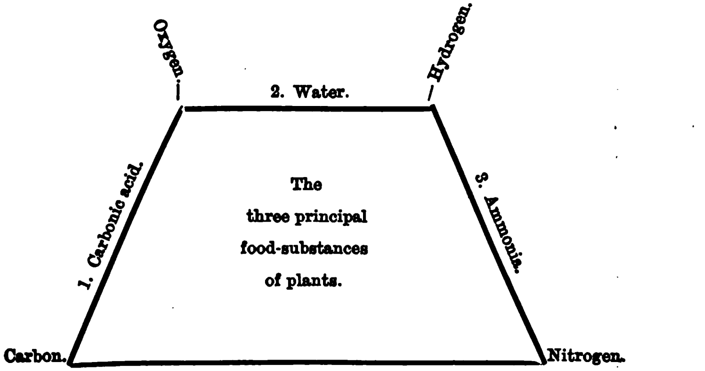

Fig. 5.—Diagramatic representation of the composition of the food-substances of plants.

The carbonic acid finds its way as a gas into the pores of the leaves. The ammonia, more carbonic acid, and water are washed in through the spongioles of the roots. In mouldering soils there are always large quantities of both carbonic acid and ammonia, either carried down into them by the rain, or in process of being independently formed from the decaying organic substances that themselves constitute the mould.

The two binary compounds, liquid water and gaseous ammonia, and the binary uncombined admixture, air, all so indispensable in the rudimentary operations of vegetable elaboration, are themselves exclusively constructed out of the three most abundant, and, indeed, omnipresent, gaseous elements of material nature. This relation, again, may be advantageously presented to the eye by means of a simple diagram, which can be taken in at a glance, and may be easily remembered.

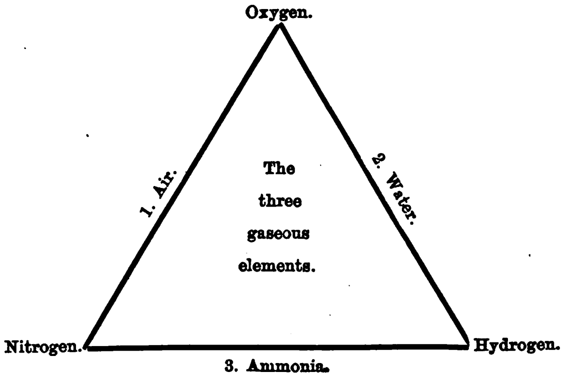

Fig. 6.—Diagramatic representation of the composition of water, ammonia, and air.

One of the marked characteristics of chemically active oxygen is that, by combining with pure metals, it converts them into a series of bodies, distinguished technically as oxides. The formation of rust upon iron is one of the most familiar instances of this action. The rust is properly oxide of iron. The rusting of the iron is due to the metal taking to itself oxygen out of the air, and combining its molecules therewith. It is a matter of some interest, in connection with the subject of metallic oxidation, that hydrogen is now conceived to be of a metallic nature. It appears to be really a metal that exists naturally upon the earth in a vaporous state, and that is never condensed into the solid form, as a simple element, under any of the conditions which prevail at the terrestrial surface. This notion results from the circumstance that hydrogen behaves like metallic bodies where it is separated from compound substances by the decomposing agency of electrical currents, and that it combines with certain metals, such as iron platinum, and especially palladium, when they are red hot, and forms with them a kind of alloy, as only a metallic substance should do. These metals absorb hydrogen when red hot, and give it off again as a gas when they cool. Iron is capable of absorbing in this way nearly the two-hundredth part of its own bulk of the gas, platinum nearly four times its own bulk, and palladium 935 times its bulk. Hydrogen thus groups itself with the metals when it is subjected to this interrogation.*

But if this view be correct, then water is a metallic oxide. It would thus appear that the vapour-like metal, hydrogen, forms a fluent liquid oxide, and that the oxide of the dense element, carbon, is a still more fluent and readily mobile gas. It is well worthy of note that it is under the provisions of this chemical peculiarity two out of the three principal food-substances of plants, specified in the preceding paragraphs, acquire their capacity for easy transport into the minute chambers of growing vegetable structure. The conversion of the light, metal-like, and highly inflammable vapour, into a limpid liquid, capable of dissolving into itself the two gaseous food-substances, carbonic acid and ammonia, without exercising any chemically disturbing action upon them, is a most important circumstance in regard to the working out of the mechanism whereby material structure becomes vitally organized. The conversion, in the laboratory of vegetable activity, of the same light, metallic vapour into ammoniacal gas, by enforced union with inert and reluctant nitrogen, and the part which this volatile agent performs in arresting the nitrogen, as it is set free during organic decomposition, and turning it back for renewed service in the constructive operation of plants, is scarcely less wonderful as a correlative incident in this admirably adjusted scheme of vital elaboration.

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* It is conceived by the chemists that if metallic hydrogen, or hydrogenium, as it is proposed that in that state the element should be called, could be procured in the solid condition, it would be found to be somewhat analogous in its properties to the metal lithium.

By far the larger part of the structures and organic products built up by living plants are formed of these four elementary principles which are the primary ingredients of water, carbonic acid, and ammonia. There are, however, eleven other elementary bodies mingled in the smaller quantities with these primary and most abundant constituents; those, namely, which are known to the chemists as—1, potassium, the metallic base of potash; 2, sodium, the base of soda; 3, calcium, the base of lime; 4, magnesium, the base of magnesia; 5, aluminium, the base of alumina, or clay; 6, silicon, the base of flint; 7, phosphorus; 8, sulphur; 9 and 10, the metals iron and manganese; and, 11, the gaseous element chlorine, which is a kind of first cousin to oxygen, and which combines with sodium to constitute common salt. The whole of these subordinate ingredients are carried into the interior of the plant by water, they are first reduced into a soluble condition by being united with oxygen, or more or less compounded together, and are then washed along in this fluent state through the spongioles of the rootlets, and up into the chambers of the stems and leaves. The different kinds of elaborated substance that are formed in the interior of living plants, to a very large extent depends upon the selection and working in of the proper amount of these several ingredients.

LECTURE III.

Food-Substances and Digestion.

WHEN the various ingredients required by the plant for the construction of its textures and elaborated products, have been collected and washed in the dissolved and fluent state into its interior channels, they are gradually passed along through the tubes and cells until they at last reach the transparent chambers of the outspread leaves, and are in them exposed to the influence of daylight and sunshine. The sap is then thickened by the exhalation of aqueous vapour, by the discharge of oxygen through the stomata of the leaves, and by the rearrangement of the molecules of the condensed matters left behind with the carbon within. The green colour of the leaf is one of the results of this process of condensation and rearrangement. It is caused by the presence of a vast number of little solidified grains,* which are constructed out of the sap, and deposited within the cavities of the leaf-cells. Numerous other kinds of vegetable fabric are built up in a similar way, the precise character in each case depending upon the specific arrangements of the ingredients. The molecules of these various products of vegetable life and activity are always of a more or less complicated nature; that is to say, a very considerable number of constituent atoms are filled and grouped together for the construction of any single molecule. In the green granules which are developed in the leaf, it appears that certainly not less than forty elementary atoms, some of one kind and some of another, are combined for the formation of each molecule. But in another product of vegetable elaboration, which appears more or less in all living plants, and which is termed gluten, or fibrin—in consequence of the glutinous character of the deposit, and of its readiness to adhere into long, tenacious fibres or threads—a still higher degree of complexity is manifested. Skilful and distinguished chemists hold that as many as 225 distinct elementary atoms, and those of five different kinds, are required for the construction of each single molecule of vegetable fibrin; that there are in the composition of each such molecule 112 atoms of hydrogen, 22 atoms of oxygen, and 18 atoms of nitrogen, worked up into a more or less solid state with 72 atoms of carbon, and one atom of sulphur.

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* Known as chlorophyl grains.

Symbol expressing the chemical composition of each molecule of vegetable fibrin, $H^{112}O^{22}N^{18}C^{72}S$.

If this view be correct, 72 molecules of carbonic acid, 29 molecules of water, 18 molecules of ammonia, and 1 molecule of sulphur, would be required for the fabrication of each molecule of vegetable fibrin, and 151 atoms of oxygen would have to be got rid of as redundant.*

The vegetable fibrin, formed in living plants, is largely used for the construction of their own textures. The walls of the minute chambers and cells are chiefly constructed by a slight further condensation and flattening out of this plastic substance. But considerable quantities are also laid by as a fixed store for future exigencies, especially in the production of seeds. Gluten is deposited in the seed around the young germ, just as albumen is deposited around the yolk of an egg, to be drawn upon as the first nourishment of the developing plants, before it is able to acquire its supply of food by means of rootlets and leaves, just as albumen is deposited round the yolk of an egg to serve as the first food of the developing bird. Thus, about eleven per cent. of the substance of wheat is dense gluten, or fibrin, which has been stored away in the grain. In one pound of wheat there is nearly an ounce and three-quarters of gluten, which may be easily procured from it, after it has been ground into flour, by washing all the other less adhesive ingredients away in a stream of water whilst it is being kneaded together by the hand.

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* It should, however, be understood that the analysis of organic bodies of this high order of complexity is a very difficult and delicate operation, and that there is, therefore, some difference of opinion amongst chemists as to the exact result obtained, although there is no question as to the fact of a very large number of atoms being contained in each complex molecule, and of the actual composition being very much like that which is given.

Various modifications of fibrinous substances are produced by different kinds of plants. But they are all of very nearly the same character as the fibrin of wheat, that is, they are of a tough, tenacious, or glue-like consistence, eminently adapted for being moulded into more or less enduring fabrics; of being plastered, as it were, into membranous sheets, and stretched into fibres. For this reason, fibrin, in all its diversities, is spoken of as a *plastic*, or mouldable substance. It is the finished material prepared for the building up of plant structure. It also appears to be the presence of nitrogen in its molecules which confers upon it this organizable property. The exceedingly complex composition of its molecules is certainly concerned with the result, for the other products of vegetable elaboration, which have molecules of simpler construction and no nitrogen among their ingredients, are incapable of being turned to the same constructive account. The entire series thus marked by the presence of nitrogen, and by readiness to be moulded into definitely organized form, is therefore classed together as a naturally allied group, all the members of which are spoken of as nitrogenous and plastic compounds, and also by physiological chemists, as proteids.*

Another kind of elaborated material, quite as generally and even more abundantly found in plants, is that which is familiarly known to almost every one as starch. This, too, like fibrin, ceases to be soluble in the liquid juices of the plants, after it has once been formed, and is therefore deposited in a more or less solid condition in the interior cavities of the cells. It usually, however, appears as small grains of an irregularly oval shape, floating freely in the sap, instead of being plastered into the condition of thin sheets, or long fibres; and these grains are framed of successive layers folded round each other, somewhat like the coats of an onion, but in larger abundance towards one side of the grain than the opposite one.

This starch is of a much simpler nature than fibrin. It is formed of three elementary constituents instead of five, and there are not more than 63 atoms of these in each molecule. The primary molecule of starch, of which a considerable number go to make one laminated grain, has no nitrogen in its constitution, but is entirely composed of carbon, and gaseous hydrogen, and oxygen. Thirty atoms of hydrogen and fifteen of oxygen, are associated with eighteen atoms of carbon.

Symbol expressing the chemical constitution of each molecule of starch, $H^{30}O^{15}C^{18}$.

It is, nevertheless, constructed in the plants under the same general plan as fibrin. Atoms of carbon, oxygen, and hydrogen are taken out of carbonic acid and water, and the superfluous oxygen, originally contained in the carbonic acid and water, is dismissed through the exhaling pores, or stomata. Some portion of this unnitrogenized product is at once used up in the construction of new tissue. But very much more is deposited as a fixed store in the roots, the seed, or in some other convenient portion of the plant. Thus there are nearly two ounces and a half of starch in every pound weight of the tuber of the potato. It is also present in still larger abundance in wheat grains and in wheat flour. There are something more than eleven ounces of starch in every pound of wheat. It causes the milky look of the water when flour is washed for the separation of its gluten in the manner which has been already described. The starch is not, however, dissolved in the water. Its myriad of little white grains are merely suspended in the liquid like so much sand in agitated water; and when the liquid is allowed to remain at rest in a suitable vessel, all the starch falls down to the bottom as a white sediment, and leaves the water above perfectly clear. Starch is found in greater or less quantity in almost every kind of vegetable tissue. It is procured for commercial purposes from several different seeds and roots, but most commonly from wheat, rice, and potatoes.

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* Derived from the Greek word *proteuo,* which signifies to hold the first place.

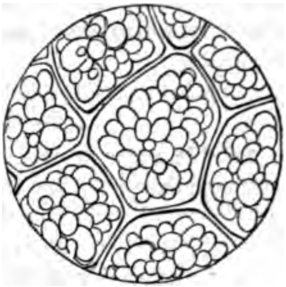
Fig. 7.—Starch grains packed away in the vesicles of the potato.

Starch, although quite insoluble in water in its fully perfected state, is very easily changed into a condition in which it is soluble. It then, however, acquires a new character. It becomes sweet to the taste, which it is not in its granular and insoluble state, and is then called sugar. This change, from the insipid and insoluble to the sweet and soluble condition, is brought about by a slight rearrangement of the atoms grouped together in each molecule. Something like six atoms of carbon, eight of hydrogen, and four of oxygen are abstracted from each, the hydrogen and oxygen no doubt in the form of water, and the carbon by being transformed into gaseous carbonic acid. There then remain 48, instead of 63, atoms in each molecule, 12 of carbon, 24 of hydrogen, and 12 of oxygen, which are probably grouped in the sugar as two molecules.

Symbol expressing the chemical composition of a molecule of sugar, $H^{12}O^{6}C^{6}$.

Soluble sugar is thus simply a less densely carbonized substance than insoluble starch. It is starch loosened out and lightened by being deprived of some portion of its solidifying carbon. Both are nevertheless so nearly alike in their chemical combination, that they can be readily connected with each other, either by adding more carbon and water to sugar, or by taking carbon and water away from starch; and, as a matter of fact, they are so connected with each other continually in the constructive operations of plants. Superfluous quantities of sugar are turned into starch when the fixed stores of matured grain are to be laid by, and starch is turned back into sugar when grain germinates in the production of fresh young plants. Sugar and starch are thus very nearly related products.

But sugar is so exceedingly soluble in water, that one pound of water will take up into itself three pounds of sugar, and will hold them in a permanent state of solution. It consequently cannot be separated from water, as starch is, by merely allowing the liquid containing it to stand at rest. The sugar can only be got back out of the water, as in other cases of actual solution, by driving the water away by heat. The sugar then remains behind, but not in the condition of grains. It reappears in the form of regular crystals. Sugar is, therefore, distinguished from starch by its proneness to assume the crystalline form, as well as by its solubility and sweet taste.

As a matter of fact, sugar is manufactured at once out of the carbonic acid and water contained in the sap and juices of plants, by the transmuting influence of sunshine, without having had any previous existence as starch. It may indeed be regarded as starch in a somewhat imperfectly-finished state, or as starch in which the process of elaboration and condensation has been stopped half way. Sugar and starch alike require both sunshine and the green vital textures of the leaf for their construction. In the presence of light, and under the influence of the green vitalized tissue, they are slowly generated in the sap-liquid of the leaves. In certain special circumstances, as in the germination of seeds and in the ripening of fruit, it is the sugar which is most abundantly produced. But the sweet, soluble principle is always present in sap to some extent. Everybody is aware how very abundantly and rapidly it is fabricated in the juices of the sugar-cane, and the beet-roots.*

Pure oil is also formed in the textures of living plants out of carbonic acid and water. When produced only in very small quantities, it is all used up in constructive work; but when prepared in greater abundance, it too is temporarily stored away in a fixed state. It is then deposited in minute drops in little sacs, or bags of membrane arranged amidst the fibrinous and amylaceous compounds of the fruit or seed. Olive oil, almond oil, and colza oil are all familiar instances. In olives, almonds, cocoa nuts, and cole seed, the oil is very abundant, and is disposed of in that way.

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* The sugar here spoken of is the variety which is produced in the grape and many other fruits, and which is known as dextrose, or grape sugar. The cane sugar is a somewhat more highly-carbonized substance, and is technically known as saccharose. Each molecule probably contains eleven atoms of oxygen, twenty-two of hydrogen, and twelve of carbon. Cane sugar is partially changed into grape sugar by digestion. Each of its molecules is apparently split up into two smaller molecules, one being of dextrose, or grape sugar, and the other of levulose, a sweet, colourless liquid, very much like grape sugar, but which submits itself less easily to the influence of ferments, and acts differently upon the vibrations of light rotating the beam when polarized to the left, instead of the right. It is this property which has conferred upon it its distinctive designation, *lævus* being the Latin word for left.

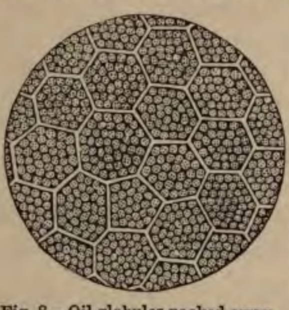

Fig. 8.—Oil globules packed away in the vesicles of the cocoa nut.

The oils formed by living plants are of a somewhat similar nature to starch and sugar, in the fact that their molecules are destitute of nitrogen. But they are very much more largely composed of carbon and hydrogen, and, in consequence, are more richly carbonized products than starch or sugar. One pound of starch contains rather less than half a pound of carbon, but one pound of olive oil contains more than three-quarters of a pound. In converting starch into an oil, the carbon and hydrogen have to be nearly doubled in each molecule at the expense of the oxygen. A starch-grain would be changed into oil by removing from it nine-tenths of its oxygen. It is on this account that oils are of such an inflammable character. They are richly endowed with the two highly combustible principles, carbon and hydrogen.

Symbol expressing approximately the chemical composition of a molecule of oil, $H^{10} O^{1} C^{12}$.

The fibrinous, carbo-hydrate,* and oleaginous substances, elaborated by plants out of the crude elements of the air and ground, are all primarily formed for the construction and support of their own organized textures—of their fibres and membranes. They are the food of the plant in its ultimate stage of preparation for the building up of vegetable structure. But it is a notable circumstance in the arrangements of nature that they serve the further purpose of furnishing food for animals as well. They are produced in such teeming abundance from the fertile soil, that there is a large superfluous store of them, available for the nourishment of animal bodies, over and above the supply which is necessary for the maintaining and multiplying of the endless generations of vegetable forms. Animals, therefore, are sustained on the superfluity of elaborated productions which the superabundant energy of plant-life furnishes.

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* The starches and sugars of food-substances are now commonly classed together as carbo-hydrates, because they are formed of carbon, and of oxygen and hydrogen in the same relative proportions in which they exist in water.

Even this bountiful provision, however, does not satisfy the needs of man when he reaches the stage of advanced civilization, and applies intelligent art to augment the abundance of nature. He then cultivates the ground, and, by artificial expedients, increases to an enormous amount such particular plants as best serve for the production of food. Above all, he multiplies the grain-yielding plants, which form stores of fibrin and starch in their seeds. As much as five million tons of wheat are produced every year to feed the inhabitants of the British Islands alone. Rice and Indian corn are also grown in enormous quantities in many parts of the world. Altogether, the weight of these three kinds of grain, produced every year by artificial cultivation, amounts to many millions of tons. The whole of this vast mass of food-substance, provided by cultivation, is destined for the support of the human beings that dwell upon the earth.

These three kinds of food-grain, which are artificially produced in such enormous quantities, are, however, not the only seeds that are used for the sustenance of living men. As a matter of fact, stores of fibrin and starch are packed away within the seeds of every kind of grass, as well as in the grain of wheat, Indian corn, and rice. Barley and oats are well-known instances to which this remark applies. There are, indeed, nearly four thousand distinct kinds of grasses, which have seeds stored with fibrin and starch. The only reason why more of these are not drawn upon as food-stores, is the circumstance that in most of them the nourishing deposits are in too limited quantity for it to be worth the trouble of cultivating them. Only those seeds which provide the nourishing substances in overflowing abundance, are made the object of the cultivator's care, and in this respect, wheat, rice, and Indian corn are in a very large degree the most convenient and productive, and on that account are selected for special attention.

Grain-crops are, nevertheless, not the only expedient which human ingenuity has devised for turning the overflowing bounty of nature to account. The vegetable food-substances, deposited in the seed, are all first fabricated in the plant. They are made, in the first instance, in the leaves by the action of sunshine upon the sap, and are then afterwards stored in a thickened state in the grain. But they are carried to the seed in the juices of the plants. The juices of the leaves and stems are consequently themselves charged with the nourishing products. It hence happens that the grass itself, in its fresh green state, is capable of furnishing food-substance for animals. Grazing animals, for this reason, can be fed upon green pastures, and grass can be transmuted into the flesh of sheep and oxen, into mutton and beef. The breeding of sheep and oxen, and the furnishing them with green and fresh vegetable food, is another of the means by which the industry and intelligence of man increase the supply of nourishment for the human race. It is in this sense that men grow butcher's meat as well as grain-crops.

The meat, which is thus produced as human food, is nevertheless only the fibrin starch and oil, which have been made by the grass and root-crops, in a somewhat transformed condition. The flesh of the grazing animal, or lean meat, is fibrin in a very pure and concentrated state; all the flesh of sheep and oxen fed by grazing is virtually extracted out of the grass. The fat is oil, which has been derived from the sugar and oil of the vegetable juices, and in that sense represents the amylaceous, or unnitrogenized part of the vegetable products. How enormously the supply of human food is increased by the expedient of setting such animals as sheep and oxen, to make meat out of grass, will be very strikingly presented to the mind, if it be remembered how many thousands of sheep and oxen are brought into the market, in England alone, in the course of a single year. In riding through highly cultivated countries, such as England is, it is wonderful to remark how every corner of the land is turned to account for the production of food for mankind, either by laying down rich pastures or by cultivating grain.

Meat is a very valuable addition to the food-resources of man. But it cannot be advantageously used by human beings without considerable additions to it of the amylaceous and unnitrogenized products of vegetable elaboration. In the wheat flour, which is converted into bread by the baker, on the other hand, both kinds of food-substance, the nitrogen-containing fibrin and the nitrogenless starch, are so adjusted and apportioned to each other, as to constitute it a food that may be advantageously used in large quantities and even, in case of emergency, that may be employed alone. In well-grown wheat, there is about six times and a half as much starch as fibrin. One hundred pounds of wheat yields sixty-nine pounds of starch and eleven pounds of fibrin. One hundred pounds of meat do not yield more than forty-two pounds of fat and about eight pounds of nitrogenized albumen and fibrin.

The real need with human beings in the matter of food, is that to each full-grown individual, something like five thousand grains of carbon, and three hundred grains of nitrogen, shall be supplied every day. These quantities are, upon the whole, most economically furnished when the food is derived from several sources of supply. Too exclusive a diet of meat gives more nitrogen than can be turned to healthy account before the five thousand grains of carbon have been received; and with too exclusive a vegetable diet, on the other hand, too much carbon has to be introduced into the body before the three hundred grains of nitrogen are secured. It is a circumstance, well worthy of note, that one pound and a half of bread, one pound of meat, and three pounds of potatoes appear to yield just the right quantity of both carbon and nitrogen for one day's needs.

The German physiologist, Ranke, ascertained by some very carefully-conducted experiments, that he continued in perfect health when he restricted himself for each day, in the matter of food, to three and a quarter ounces of meat, or of an analogous quantity of nitrogenized vegetable substance; three and a quarter ounces of fat, or its equivalent in butter and oil; seven and three-quarter ounces of dry farinaceous substance, such as potatoes, rice, and the starch ingredient of bread; three-quarters of an ounce of saline substances, salt, potash, soda, and the rest; and a little more than five pints of water, including such portions of that liquid as is ordinarily taken in intimate combination with the more solid food.

The fibrinous, farinaceous, and oleaginous products formed by the building up activities of plants,—the corn, meat, rice, and analogous substances, prepared under the beneficent cooperation of living vegetables, to serve as food for the animal kingdom—are all of a solid, or quasi-solid, and substantial nature. They are most of them insoluble, or of very slight solubility, in water, although they contain within themselves, as an important part of their own constitution, considerable quantities of that omnipresent and indispensable liquid. They have, nevertheless, to be transported by water before their task of affording sustenance to the living frames of animated beings can be accomplished, quite as absolutely as have the food-substances of plants, in order that they may reach the interior of vegetable structures. It is thus virtually true, that animals as well as plants "live by water;" that drink is an essential provision for animal, as it is for vegetable, life. The food, which affords nourishment and support to the actions of the animal frame, and which sustains it in its manifold operations through the prolonged period that extends from birth to death, has to be washed into the interior of that frame, and to be distributed in liquid streams to every part of its delicately-organized structures. The process by which this is accomplished, is much more complicated in the case of the animal than it is in that of the plant; but it is also on that account of greater interest even when viewed only in the light of mechanical contrivance. To human beings, whose privilege it is to subordinate their lives to the dictates of understanding and reason, the subject is of the very highest importance, as will presently appear.

The primary condition, which seems to have been aimed at in the arrangements of animal life, as distinguished from vegetable activity, is the provision for free movement from place to place. All animals, excepting those of a very lowly and rudimentary kind, have active limbs elaborately hinged and strung for carrying them about. Quadrupeds and bipeds walk and run upon the ground; birds fly in the air, and fishes swim in the water. It is a necessary consequence of this adaptation to locomotion that they can have no roots inserted into the ground. They have roots nevertheless for the drawing in of their food, just as much as stationary plants have, and they carry these roots about with them in their wanderings. The spongioles of these roots are grouped round the wall of an interior cavity, or membranous bag, and in this bag supplies of food are deposited at more or less frequent intervals. The food is thus carried about inside the bag, and is washed from the bag through the spongioles of the rootlets. The spongioles, in the case of locomotive animals, are, however, distinguished by a specific name. They are called villi, because they have very much the same appearance as the pile of velvet, or the nap of cloth.* The food-bag itself is termed the stomach, because it is the receptacle into which the food is poured from the mouth.† The stomach and its canal-like intestinal prolongation, are lined by a membrane that has somewhat the appearance of velvet, being covered with soft villous projections. Each little villus has a sponge-like cluster of absorbing vesicles at its tip, and a series of tubes or vessels running in from these. The most casual glance, when helped by the microscope, suffices to show how materially each of these villous projections resembles the rootlet of a plant. But each has for its sucking-in work an advantage the vegetable radicle does not possess; that is, a certain capacity for free movement,

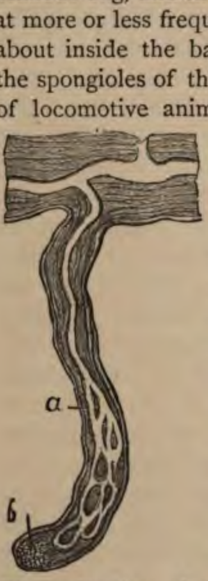

Fig. 9.—Structure of a villus of the human intestine, showing (*a*) the absorbing duct, and (*b*) the soft sponge-like sucking point.

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* *Villus*, is the Latin word for wool or nap.

† The word is derived from the Greek, *stoma*, mouth, and *cheo*, to pour.

which it turns to excellent account. Each little villus acts as a kind of sucking pump, as well as an absorbing sponge.

The stomach itself is of considerable size, so that it can hold an ample store of the food-substances submitted to its operations, and the canal into which this leads is a tube-like cavity, not less than twenty-six feet long in the adult, in order that there may be plenty of opportunity for the absorption of the liquid food, after it has passed the ordeal to which it is subjected in the wider, bag-like receptacle. The long tube is, however, gathered up into a series of convolutions and twistings, in order that it may be packed away in the body conveniently for transport.

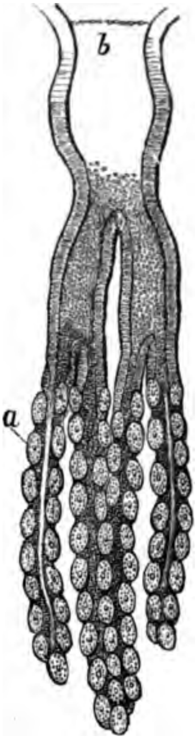

Fig. 10.—One of the glandular ducts of the stomach which secretes the gastric juice, showing (a) the clustering vesicles, and (b) the opening or mouth, which discharges the secretion into the stomach.

The substantial fibrin and farina, which are contained in the food-products prepared by the plant, are crushed and reduced in the mouth into the state of moist pulp, by the action of the teeth and saliva, and in that condition are swallowed, or, in other words, conveyed into the cavity of the store-bag, or stomach; the gullet contracting from above downwards by a kind of squeezing motion. So far the only service that is rendered by water, is the softening and moistening of the pulp that is about to be pressed down the gullet from the mouth by muscular action. But once deposited in the stomach, a further dilution of the pulp takes place; a thin, acid juice is poured out from the inner surface of the stomach, and the pulped food and this juice are churned up together by the never-ceasing play of the walls of the bag, these being abundantly supplied with muscular fibres to enable the churning action to be performed. The acid gastric juice which is added to the pulped food, is prepared in a series of elaborating chambers hollowed out in the substance of the bag.

The saliva and the gastric juice, aided by the warmth of the interior of the living body, exert a very powerful influence upon the dense materials with which they are mingled, and soon convert them into a loose incoherent mass, which is pushed down through the lower aperture of the stomach on into the intestine, and is there kept moving gently along it in close contact with its soft, velvety, villus-covered walls.

The saliva serves principally to convert starch, in its several diversities of form, into 'soluble sugar, and so facilitate its transport by water. Bread tastes sweet when it is eaten, because the starch which it contains is converted into sugar by the influence of the saliva in the mouth. A similar change is produced in the albuminous ingredients of the food, such as the gluten of bread, and the fibre of meat, by the gastric juice. They also are changed into a soluble substance, which is termed peptone.* Two other liquids are added to the dissolving pulpy mass, as it glides along the alimentary canal—a yellow liquid, of a somewhat soapy consistence, known as the bile; and a clear, viscid liquid, termed the pancreatic juice. These are fabricated in two large glandular organs, the liver and the pancreas,† provided for the purpose, and placed just below and behind the stomach. The bile and the pancreatic juice are poured out into the alimentary canal a few inches beyond the stomach, by ducts which open there into the canal. As the acid pulp is pushed along past the opening or outlets of these ducts, bile and pancreatic juice are mingled in considerable quantities with the mass. The soap-like bile, which contains a certain amount of free carbonate of soda, immediately neutralizes the acid remaining in the mass, and enables the pancreatic juice to complete the conversion into sugar of such portions of starch as have escaped the influence of the saliva, and at the same time to finish the fabrication of soluble peptone from the digesting albumenoid substances. The bile and pancreatic juice also enable fatty matters and oil of all kinds to be changed into a white, milk-like emulsion, capable of being intimately mingled with water. The white, milk-like liquid very soon begins to separate itself from the coarser parts of the pulpy mass, and is then recognized as "chyle."* The milky chyle having been brought into contact with the fine pores and channels of the velvet-like pile, or villi, of the alimentary canal, is drawn up through their spongy tips (*b*, Fig. 9), just as the nutritive solutions are drawn up into the spongioles of the roots of plants. The liquid essence is next collected from all the innumerable villous projections scattered along over the lining of the canal, by a complete network of tubes lying spread within its membranous wall, and is so passed on into channels, or ducts, that grow larger and larger as they go, until they all finally terminate near the backbone in one common receptacle, or vessel, which runs up through the chest, and at last empties itself into one of the large veins, almost immediately before it enters the heart. At this point, the chyle, the fresh, milk-like emulsion extracted from the food by digestion, is mingled with the blood.

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* The term "peptone" is derived from the Greek word *pêpto,* which signifies to digest. Peptone is the substance produced by the digestion of plastic, albuminous, and fibrinous food.

† The pancreas is so named because it is a large flesh-like body; the word is derived from the Greek *pan,* all, and *kreas,* flesh.

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* From the Greek word *kulos*, which signifies juice, or humour. When the chyle was first noticed it was considered to be the chief essence extracted from food by digestion.

But the living body does not entirely rely upon the operation of this ingenious arrangement of special collecting vessels for the supply of its sustenance. Some portions of the food, liquefied by digestion, enter the channels of the circulating blood in a still more direct way.

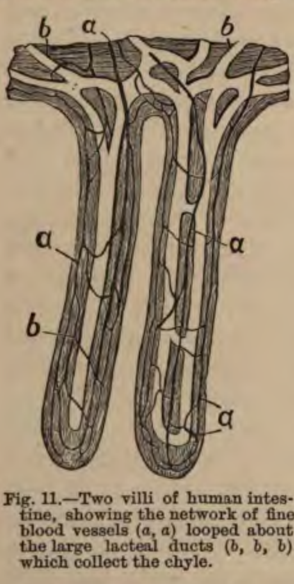

Fig. 11.—Two villi of human intestine, showing the network of fine blood vessels (*a*, *a*) looped about the large lacteal ducts (*b*, *b*, *b*) which collect the chyle.

Every little villous projection of the inner membrane of the alimentary canal has a looped network of blood-vessels investing its central, absorbing duct. A small artery enters each villus, and branches itself out into an intermeshing network of capillaries, or hair-fine vessels, which, in their turn, are afterwards gathered up into a single vein that turns back out of the villus.

During the continuance of life, blood is constantly flowing, under the strokes of the heart, in a never-ceasing stream, through these meshed loops of the blood-vessels, entering by the arterial trunks, permeating their capillary branches, and then pouring on, and out, by the venous trunks. But as the blood flows in this way through the capillary vessels of the villi, it is only separated from the internal surface of the intestinal canal, which is bathed by the dissolving and liquefied food, by fine films of porous membrane. Portions of the liquefied food consequently soak through into the interior of the blood-vessels, mingle with the streaming blood, and run on with it in its appointed course.

As a general rule, it is the thinner parts of the liquefied mass which are drawn into the vital parts of the organization by this direct route through the blood-vessels. The thicker and more viscid portions have to be taken charge of by the chyle ducts. The white, milk-like aspect of the chyle is in reality due to its being in this more viscid condition. It contains the greater portion of the oily ingredients of the food, which do not freely dissolve as clear solutions in water. When a small drop of the chyle is examined by the microscope, it is seen to consist of an infinite number of white specks, termed the molecular base, with a few larger corpuscles floating in their midst.

Each one of the small white specks is an exceedingly minute droplet of oil, ensheathed in a covering of albumen, which has been deposited round it as a filmy coat. The larger corpuscles contain some portion of the more plastic, albuminous, or fibrinous ingredients of the food, and are gradually built up in the chyle during its passage from the villi and along the ducts. The vessels which carry the chyle are called Lacteals,* on account of the white milk-like appearance of that liquid.

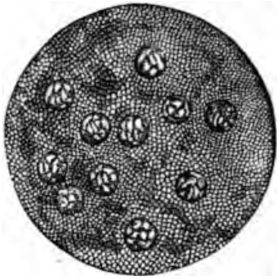
Fig. 12.—Chyle corpuscles floating amid the minute granules of the molecular base.

Digestion is thus, in the main, the conversion of insoluble, albuminous substances and starch into soluble peptones and sugar, and the suspension in water, in an emulsion-like form, of the minute globules of oil and fat which cannot be made actually soluble, in order that the soluble peptones and sugar may be drawn into the delicate blood-vessels of the intestinal villi, and the emulsified oils and fat be taken in a similar way into the coarser pores and channels of the lacteals lying within the embrace of those vessels. The chyle, passing into the larger ducts, is in all probability accompanied by some portion of the more soluble products of digestion which flow in greater abundance immediately into the blood-vessels.

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* From *lac*, the Latin word for milk.

The completion of this complicated process, as a matter of course, requires a certain amount of time. With most people it is not until something like a couple of hours after a copious meal that the softened pulp begins to be passed onwards out of the first chamber, the store-bag or stomach, where the maceration of the loosening mass is, in the main, carried on; and, at the very least, another three hours must elapse before the most stubborn and refractory of the ingredients of the food are sufficiently softened and dissolved to be in their turn discharged into the intestinal canal. Hence the undesirability of feeding at too frequent intervals. If a fresh meal be introduced into the stomach before the old one is thoroughly pulped and dismissed, this can only be at the cost of overloading and oppressing the working parts of the apparatus.

There is obviously a limit to the amount of saliva, gastric juice, bile, and pancreatic juice that can be fabricated within the duration of a single day, for the work of macerating and pulping which has to be performed. As a matter of fact, some portions of the food are very commonly passed on before they are completely prepared for transmission into the deeper recesses of the living mechanism as they ought to be. Also, in the ordinary indulgence of luxurious life, more food is constantly taken into the stomach than the mere support of the vital actions of the economy requires. The furnace then has to be, as it were, burned at too great a rate, and high pressure has to be put upon those contrivances of the mechanism provided for the removal of waste and excess, which have to be hereafter alluded to in more detail. A certain measure of excess of this kind is effectively remedied by the compensatory powers of the living economy. But more serious disorder is at all times apt to be brought about when the excess is carried beyond the limits that can be thus satisfactorily dealt with. For this reason the well-known old adage, "Enough is as good as a feast," may be advantageously modified for physiological purposes into a new form, and made to read, "Enough is *better* than a feast."

LECTURE IV.

The Composition of the Blood.

It will be observed how important a part the great agent of transport, water, has to play in the series of operations which were described in the last Lecture. At every stage, liquids, or aqueous solutions, are employed. There is the liquid saliva produced in the mouth; the liquid gastric juice poured out in the stomach; the liquid bile, with the pancreatic juice, and some other associated secretions, furnished in the intestine; and, finally, the liquid chyle and the liquefied peptones and sugars, which are the perfected essence of the digestive transformations. All these liquids are chiefly composed of water, which, being largely employed in the fabrication of the whole of them, must therefore be freely supplied. This is the one reason of the paramount necessity of drink for animals, as it is also why, in every kind of drink that is employed, water must be the chief, when it is not the sole, ingredient.

The stomach itself has no villous projections upon its inner membrane, because there are no soluble products of digestion at any time within it to be absorbed. Such are not formed, during the digestion of the food, until the bile has been added in the intestine, to the softening and dissolving mass, nor can the oily ingredients of the food be arranged into the finely-diffused, albumen-coated drops or spherules which have been described, until they have been subjected to the same influence. But the walls of the stomach can drink in the liquid substances that are introduced into the cavity, and, above all things, they can absorb, at once, and with the most eager avidity, the very thin liquid, water. In order that they may be capable of doing this, the inner surface is everywhere covered with a network of capillary blood-vessels, in all essential particulars like those which are looped over the chyle ducts in the villous projections of the intestines.

The circulating blood is at all times streaming through this network of delicate vessels, entering them by arterial branches and escaping from them by veins; and, as it does so, thin liquids, like water, soak in through the fine films of the vessels, and mingle with it. This process occurs with such exceeding rapidity that salts, like iodide of potassium, which make thin solutions with water, have been found in the most distant parts of the structures of living animals within a minute of the time when they have been so introduced into the stomach. It is by this direct route, indeed —the fine blood-vessels of the stomach—that drink is supplied to the system. Food, which needs to be digested and dissolved before it is liquid enough to traverse the fine channels of the living body, goes in by the roundabout way of the convoluted intestines and the villous rootlets projecting into their cavity. But water, which is already as liquid as it can be, passes at once from the stomach to the blood without having to go through the tortuous track of the intestine, or to encounter for that reason the ordeal of even

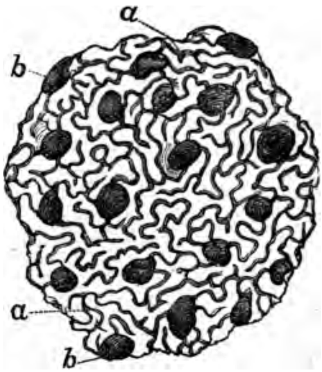

Fig. 13.—The network of fine blood-vessels (*a*) distributed on the inner membrane of the stomach around the orifices of the pits (*b*) that furnish the gastric juice.

temporary delay. Only as much of the great agent of transport is spared for the roundabout path as is indispensable for the liquefaction and conveyance of the denser ingredients of the food. The rest is summarily taken through the flood-gates of the broad, gastric surface into the coursing current of life.

The liquefied extracts of the dissolved food, after they have been sucked into the absorbing rootlets and netted vessels spread out over the walls of the digestive canal, are poured with the returning currents of the blood into a rhythmically contracting force-pump, which, by its unceasing movements, at each stroke ejects a crimson stream onwards into a large arterial tube, prepared to serve as the great supply-pipe of the frame. The blood is pumped through an elastic tube to all parts of the body, very much as water is artificially supplied to the beds of a well-kept garden, through an india-rubber hose. But the hose, in the case of the living body, does not run simply to one spot. It branches out from the trunk into smaller and smaller ramifications, until at last every fibre and membrane of the living structure is penetrated and deluged by the stream. The final branches of the hose are scattered out like the twigs and leaf-veins of a tree. But they are so numerous and fine, that they can only be seen by a powerful microscope. When the thin transparent web which connects the toes of the frog is properly stretched before the lenses of a microscope, not only can these ultimate branches of the great supply-artery

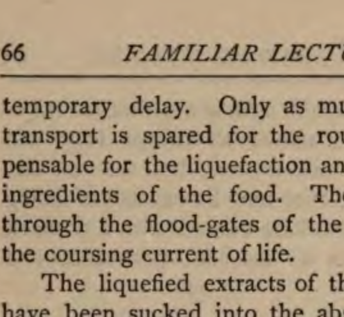

Fig. 14.—The capillary blood-vessels and blood-corpuscles seen, greatly magnified, in the web of the frog's foot, *a* being the termination of an arterial trunk, and *b* the beginning of a vein.

of its body be seen, but also the current of blood rushing along through their hair-fine channels under the stroke of the force-pump.

This spectacle of the movement of the living blood, in its actual routine progress, is one of the most beautiful of the revelations that the microscope has made to the eye of man; but in order to realize all that the instructive exhibition implies, it must be understood that, in this instance, the moving stream is only seen because it chances to be passing through a thin film, which, in consequence of its transparency, can be penetrated by the sight; and that exactly what is taking place there, where it can be seen, is also occurring everywhere in the deeper and more hidden parts of the structures of the animal, and therefore also in the living bodies of men. The whole solid fabric is being continuously flushed with a coursing stream of blood, which is so abundantly and so universally diffused, that the point of the finest needle cannot be pushed into any of the soft textures of the frame without encountering and wounding some little tube of the capillary net-work. When this diffusion and never-ceasing movement of the blood are properly comprehended, there will no longer be any difficulty in understanding the importance of the part which water has to play in the actions of the living economy. It is the great agent of transport in this exquisite plan of supply. The blood is the rich extract of the food, provided for the continued sustenance of the frame, suspended in a copious deluge of water. In sixteen pounds of blood, which is probably not far from the quantity that is flowing in the body of a full-grown human being at any one instant of time, about three pounds and a quarter of the weight are made up of the denser and actually nourishing parts of the liquid, and twelve pounds and three-quarters are pure water, employed mainly to confer free movement on the mass. The nourishing food is thus literally washed into the flesh, the nerve-pulp, the skin, and even into the gristle and bone of living animals; and, in that sense, the animal is living upon its drink, as without the liquid water of that drink, no such washing in of substantial nourishments, through the branching vessels and supply pipes, would be possible. The force-pump, which by its rhythmical contractions sustains this ever-running current of the blood, is a thick, fleshy bag made up almost entirely of muscular cords, that alternately lengthen and contract. When these cords lengthen, they expand the general size of the bag, and thus tend to leave a cavity within. When they contract, the interior cavity is effaced. The contracting and dilating bag is the fleshy mass which is known as the heart, and which is suspended by firm attachments in the middle of the chest, where its strokes of contraction may be felt by the shocks which they cause when the hand is laid upon the ribs. The blood is driven out through a large arterial trunk when the muscular walls contract, and it is poured in through another opening, supplied from the veins, when the contraction is relaxed. There are valves so arranged at these several openings that the stream can only flow in one direction. Each contraction of the fleshy walls closes the valves of the inlet, and opens the passage into the outlet. The dilatation, on the other hand, produces an exactly opposite effect: it draws back and closes the valves of the outlet, and leaves free the inward passage from the veins. The cavity of the heart, when its fleshy walls are extended, is large enough to receive about six ounces of blood. Something like six ounces are, therefore, pumped out at every stroke. But the heart beats, upon the average, from seventy to eighty times every minute. Therefore, in each half minute of time, not less than from thirteen to fifteen pounds of blood, which is about the quantity that should be contained in a full-grown man, is issued from the heart. The entire blood of a living human being thus passes through the heart something like one hundred and twenty times every hour, or nearly three thousand times in twenty-four hours.

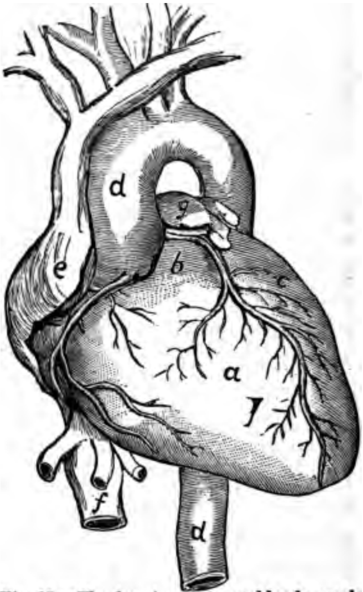

Fig. 15.—The heart and large blood-vessels of the human body; *a* being the right ventricle, which sends the blood through the pulmonary artery (*b*) to the lungs; and *c* being the left ventricle, which sends the blood through the large artery (aorta) (*d*) to supply all parts of the body; *e* is the auricle which receives the blood at large through the venous trunk *f*; and *g* is the auricle which receives the blood from the lungs.

But, if the heart beats 70 times in a minute, this implies that it does the same thing 4,200 times in an hour, 100,800 in twenty-four hours, more than thirty millions of times in a year, and more than two thousand, five hundred millions of times in a life of seventy years. The muscular force, which is used in each of these contractions, is also very considerable, in order that the blood may be squeezed through the vast myriads of minute tubes to which the main supply-pipe leads. It has been found by experiment that it amounts for each stroke to a pressure of about thirteen pounds on the entire column of blood. This, allowing for the action of both sides of the heart,* is a force that would be capable of lifting, every twenty-four hours, something more than 120 tons, one foot high.* It may, therefore, be conceived how enormous is the expenditure of force made by a single human heart during a life of seventy years. Yet the wonderful organ is in very many instances not worn out after the unceasing exertion and prolonged efforts involved in that period of time. As a piece of moving mechanism, it is capable of at least two thousand five hundred millions of strokes before the perfection of its structure is in any material degree impaired. The reason for this, however, is that, as a matter of fact, its substance is repaired as rapidly as it is worn. Branches from the great supply-pipe of nourishment, which are called coronary arteries, because they encircle the heart like a coronet, or garland, enter the walls of flesh, and penetrate everywhere amongst the contractile fibres, as the network does within the web of the frog's foot. The blood from the minute vessels of this network gives back to the hard-working fibres of the heart, whatever of their material is used up in the effort of the movement. This particular instance furnishes an apt and striking illustration of the way in which the sustenance of living structure is managed. The heart pumps liquid nourishment to its own substance as well as to the other parts of the frame. If the inside of its fleshy walls could be seen in the same way as the transparent film of the frog's foot, it would be found that it was flushed with one continuous deluge of crimson blood, which enters its fleshy substance by arteries, and flows out from it by veins, and never ceases its streaming progress, for even an instant, so long as the actions of life are maintained. For seventy years and more, that even flow goes on without a break. If at any time the streaming movement stops, it is because the heart has ceased to beat, and when the heart ceases to beat, it means that life has passed into death.

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* The heart in reality consists of a double chamber. There are two hearts of similar construction joined closely together. The object and reason of this will be more fully referred to presently.

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* The lowest estimate that has been made is here given. Some modern authorities consider that the heart of a full-grown, vigorous, and healthy man, performs work that is equivalent to lifting 240 tons one foot high.

The crimson blood, which is pumped out from the heart, through the branching arterial vessels, to all parts of the living frame, is the nutritious substance procured from the digestion of the food in the final stage of preparation for its appointed work. It is the concentrated essence of the food in the process of being washed by streams of water to the organized structures of the body, through branching and widely-distributed supply-pipes. It is on account of the adoption of this liquid method of transport that water forms so large a part of the blood, and that in sixteen pounds of blood there are not less than twelve pounds and three-quarters of water.

But the most casual observation shows that the blood of the living animal consists of two distinct parts. When the streams of the blood are watched flowing along through the minute channels contained in the transparent web of the frog's foot, it is at once perceived that the moving current is composed of a quite countless myriad of small round bodies, floating in a clear homogeneous liquid, in which no distinctive structure can be perceived. The round bodies are known as the corpuscles, or little bodies of the blood. The clear liquid is termed the liquor sanguinis, or fluid of the blood. It is now also very frequently spoken of as the blood-plasma,* because it is the part of the blood from which the plastic, or structure-forming ingredients are mainly derived.

But the liquid plasma of the blood, although presenting to the eye the appearance of a simple homogeneous fluid, is in reality an admixture of four several ingredients.

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* The word *plasma* is the Greek name of the tenacious, clay-like substance which was used by the old sculptors for moulding busts and statues.

Nine parts in ten of it, estimated by weight, are water. But the water is thickened to a certain extent by the addition of three denser materials, which it holds in solution; so that a pint of this clear liquid weighs about 215 grains more than a pint of pure water. The liquid contains, in the first place, some considerable quantity of salt,—about thirty grains to the pint. It also holds in a state of solution about 300 grains to the pint of a substance that very closely resembles white of an egg, and which is technically known as albumen, on account of the white appearance it presents when it has been coagulated by exposure to the heat of boiling water. If a little blood-plasma be boiled, this albuminous ingredient coagulates and falls through the liquid as a flocculent deposit. It is, in fact, the gluten (vegetable fibrin) elaborated by the plants, transferred in a soluble state to the interior of the living animal body. It is in some degree held in solution in water by the quantity of salt with which it is mixed, and in consequence of the comparatively low degree of temperature, namely, 98° of Fahrenheit, to which the healthy animal temperature is limited.

But the plasma of the blood needs to have a certain amount of body as well as of liquidity, because it has to flow, in the extreme parts of its streaming circulation, through tubes of an exceeding tenuity, or fineness. The walls of these capillary, or hair-fine, tubes are made of the most slender films, and if only a thin solution of albumen and water were flowing along the tubes, this would exude through their films as readily as thin water filters in through the same kind of films where they are spread upon the lining of the stomach. A small quantity of a size-like substance is consequently added to the liquid.

If blood, freshly drawn from the vessels of a living animal be whisked up by a bunch of fine twigs, buffcoloured shreds are very soon seen to be clinging about the twigs. This is the adhesive size extracted out of the blood; or, in other words, the peculiar principle which is known as fibrin, on account of its habit of readily forming into threads. It is so easily converted into an adherent, solid mass, that it does not require the heat of boiling water, as albumen does, to produce coagulation. It is nevertheless very similar, indeed, in its material constitution, to albumen. The chemist can scarcely find any difference between the two.

Fibrin is merely albumen pushed a small stage further on towards the condition of living animal substance, and is formed out of the albumen, but only in the channels of the living animal structure. It is, therefore, in this respect distinct from the more crude preparation which is distinguished by the same name amongst the productions of vegetable elaboration. Vegetable fibrin is more nearly allied by intrinsic properties and nature to albumen, than to its animated namesake. Animal fibrin is the plastic material of the food advanced almost to the threshold of living existence. As, however, the fibrin of the blood has still to continue its streaming progress in the narrow tubes of the apparatus of supply, it is very carefully limited to the quantity which is convenient for flowing. This does not amount to more than fifteen grains in each pint of liquid plasma, unless in certain disordered states which tend to sluggish movement, stagnation, and undue clotting of the blood.

In some disorders of an inflammatory and rheumatic character, the fibrin preternaturally increases in the blood until there are between forty and fifty grains in each pint of plasma. As a general rule, and in the proper balance of vigorous health, fibrin is gradually formed out of the albumen in the blood just rapidly enough to keep up the proportion of fifteen grains to the pint, and to restore the amount that is taken out of the blood for purposes of organic construction. It is a notable fact, which has been ascertained by direct experiment, that the size-like viscidity of the blood facilitates, instead of impeding, its flow when the amount of fibrin developed in the liquid does not exceed the proper standard of fifteen grains to the pint. It is only when it is generated in larger quantities than this, that the more sluggish movement, and more coagulating tendency begin to be experienced. When there is too little fibrin in the blood, there is generally a deficiency of formative, or organizing power. For instance, it sometimes happens, in such circumstances, that wounds are very slow to repair themselves and difficult to heal.

This highly plastic material, matured within the blood out of the albuminous principles of the food, appears to be formed by a process which can now be to some extent traced by the observation of the chemist. Intermediate states, in its preparation, have been distinctly followed in the blood, which are obviously only to be realized in the vital laboratory. Two distinct and highly complex principles,* are first formed, which are both highly soluble in dilute saline solutions, and which neither of them coagulate alone. But they immediately thicken into coagulated threads when they are mixed together, and especially when this mixture occurs in the presence of a ferment that is prepared in very minute quantities in the blood.

There is another still more important ingredient of the blood, which is matured out of the nutritious principles of the food, after they have been introduced into the channels of the living animal body. When the streaming blood is watched flowing along in the netted vessels of the web of the frog's foot, it at once becomes apparent to the observer that the motion is followed by the eye, because a number of exceedingly minute, round corpuscles, or little bodies, are carried along in the stream. If the flowing liquid were clear and transparent throughout, its movement would not be appreciated, or caught by the eye. It is only perceived because floating specks, which are distinct objects in themselves, are plainly seen to be carried along in the stream. (See Fig. 14.)

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* These intermediate substances, which are mixed to produce coagulable fibrin in the blood, are called paraglobulin, or fibrinoplastin; and fibrinogen, or the generator of fibrin.

These corpuscles are constructed out of the plasma of the blood. They are so very minute that they require to be largely magnified before they can be seen. But they are, nevertheless, very elaborately and definitely finished structures, all of precisely the same dimensions, and of the same shape and character. They are round, flattened discs, slightly pinched in at the centre, and are of a distinct red colour, although the plasma, in which they float, is colourless and clear. They may be very beautifully seen, with high magnifying powers, if a minute speck of blood, upon the point of a needle, be mixed with a little weak solution of salt, and the mixture be then exposed to examination by the microscope. They are so thickly crowded together in the blood, that they cannot be satisfactorily observed until, by this contrivance, they are made to separate themselves and float apart.

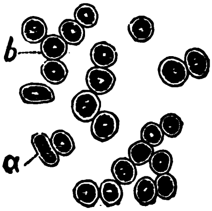

Fig. 16.—The red corpuscles of human blood, highly magnified, seen edgeways at *a*, and in full face at *b*.

For a long time it was conceived that these corpuscles of the blood were hollow cases, made of fine, horny films, and charged in their interiors with a red liquid. It has, however, quite recently been shown that they are fibrinous bodies of a porous nature, with their pores filled up by a pasty, red-coloured mass. The porous mould of the cor puscle is termed the "stroma,"* or bed, and the red colouring substance deposited in the pores, is now known to be a product of living organization of very considerable importance in the operations of the animated economy. It is therefore distinguished by a specific name, and called the hæmoglobin.

The red colouring matter of the blood,† this hæmoglobin, is a very complex substance indeed. It is remarkable, amongst all other compounds built up by animal organization, in having iron amongst its ingredients. But the iron is in very minute quantities. The dried hæmoglobin contains but a little more or less than a half per cent. A single atom of iron appears to be associated for the construction of one ultimate molecule of hæmoglobin, with not less than 1896 other elementary atoms; of which 960 are hydrogen, 600 carbon, 179 oxygen, 154 nitrogen, and 3 sulphur.‡

Symbol expressing the chemical composition of a molecule of hæmoglobin, $H^{960}O^{179}N^{154}C^{600}S^{3}Fe^{1}$.

There is also the further notable peculiarity in the chemical characters of hæmoglobin, that a considerable portion of the oxygen, which it contains in its most perfect form, is only loosely attached to the mass constructed by the congeries of the other elements; so that it can be alternately added to and taken away from that mass, without destroying the structural integrity of the body to which it is temporarily attached. The molecule, indeed, is primarily used as a carrier of oxygen. It is employed in the streaming blood to convey supplies of unchanged oxygen from place to place. It is, however, distinguished by a different name when its burthen of oxygen is complete, being then called oxy-hæmoglobin. The principle, like some other chemical compounds that are now known, is conceived to have two distinct states of existence marked, the one by abundant, and the other by sparse, oxidation. The oxygen, which is derived by the respiratory process from contact with air in the lungs, is linked with the other ingredients by ties so readily broken, that it can be given up to other more easily oxydizable bodies when it comes into contact with them in the innermost recesses of the frame. The important consequences of this particular relation to oxygen will have to be again alluded to.

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* From *stroma*, the Greek word for a stratum or bed.

† From the Greek words *haima*, blood, and *globos*, a ball. The matter which chiefly forms the balls or globules of the blood.

‡ This very complex constitution has to be assumed by the chemist, for the ultimate molecule of hæmoglobin, because the single atom of iron, which is associated with this large cluster of the other elements, is conceived to be a final and indivisible atom. An indivisible atom would have to be divided amongst the molecules, if more than one were formed out of this group of primary constitutents.

The red colour of the blood of living animals is entirely dependent upon the presence of this richly elaborated material stored away in the pores of the corpuscles. These little bodies, indeed, are essentially cases provided for its reception and convenient storage. They are, nevertheless, of such exceedingly minute dimensions, that it requires some considerable effort of thought to arrive at anything like a correct appreciation of their smallness. They exist by millions in the minutest droplet of blood that can be taken up upon the point of a needle. The red opacity of the blood is due to the way in which they crowd in quite incalculable myriads upon each other. About 3200 of them can be laid side by side within the span of an inch; about 12,400 of them could be packed edgeways, and face to face, in the same extent; something like 50,000 of them could be pavemented round the head of a pin; nearly five millions could lie flat upon the face of threepenny piece. But, as there are at least sixteen pounds of blood in the body of a full-grown man, and as one-half of that by weight, in the most vigorous state of health, is corpuscles, this implies that there must be a sum total of 22,500 milliards (reckoning each milliard as one thousand millions, —1000,000,000) contained in the body of a living, human being.* And, in addition to this, it must be further remembered that these wonderful bodies are being continually reproduced in successive generations, often for a period exceeding seventy years, before the number of them concerned in the support of a single human life has been taken into the account.

The minute corpuscles of the blood are the first products of structural organization effected in the body of living animals. Diminutive as they are, they are structures built up on a definite plan, and fashioned for the performance of a specific task in the economy. They are, indeed, in a certain sense, endowed with life. Each little corpuscle is a living object, with a career and a destiny of its own. It grows out of the plasma of the blood. How, in the first instance, it is formed out of this plasma, it is not yet possible to say, this being one of the mysteries of life which have not yet been fathomed by the investigations of science. But it is at any rate clear that the corpuscle is formed in the blood, and is a product of some subtle force brought into play in the body of the living animals, and in no case capable of producing any similar result externally to it.

Although the red corpuscles of the blood are carriers of oxygen, this, it must be remembered, does not in any sense militate against what has been said of water being the great agent of transport in living structures. The corpuscles, which carry the oxygen, are themselves transported by the flowing streams of a thin, watery liquid. They are like boats freighted with cargo. But, over and above this, they are themselves very largely made up of water, even in their essential framework. In a pound of red corpuscles, separated from the plasma in which they float, more than ten ounces of the weight is due to the water which they contain. In the liquid plasma itself, eight-ninths of the liquid is made up of water. In one pound of plasma there are something more than fourteen ounces of water. Taking the blood as a whole, corpuscles and plasma, in every pound very nearly thirteen ounces are pure water. In sixteen pounds of blood, thirteen pounds are water, the other three pounds being made up of the solid ingredients that are contributed from the food to thicken the plasma and to build up the corpuscle.

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* The enumeration in figures of the number of corpuscles contained in the blood of a full-grown human being, is 22,500,000,000,000. This is a quantity which counting at the possible rate of 200 per minute, it would take 242,413 years to reckon up.

The red corpuscles of the blood, however, are not the only kinds of structural bodies that can be detected floating in the liquid plasma. There are associated with them, but in much smaller numbers, another kind of corpuscle, which is known to physiologists as the colourless corpuscle, because it is entirely destitute of the coloured principle that is stored in its red associate. The colourless corpuscle is of slightly larger dimensions than the red. But it is by no means as fixed in form. It changes its shape not unfrequently even whilst it is being looked at, and has a power of spontaneous movement in its own substance which confers upon it the capacity to push out finger-like projections. In consequence of this faculty of changing its shape, it is able to insinuate itself into very minute apertures and pores.

This colourless corpuscle is even more obviously a living body than its red-coloured associate. There is never more than one colourless corpuscle to every four or five hundred of its red companions. It is not easy to trace the origin of these curious bodies in the streaming blood, but they are known to be increased in number shortly after the taking of food, and are certainly formed out of its more plastic ingredients. Occasionally not more than a single colourless corpuscle can be found in a group of 800 coloured ones, and then suddenly the number appears to be doubled. The purpose to which these protean and changeable structures are destined, after they have been made in the blood, is not as satisfactorily ascertained, as in the case of the red corpuscles. But it is probable that they have something to do with the fabrication of fibrin out of the albuminous ingredients of the blood-liquid. They are themselves only produced after the liquefied food has been passed through a series of glandular structures, on its way to be mingled with the blood, and the young forming blood seems to be incapable of coagulating until they are present in it.

When blood is allowed to flow out of a wound made in the vessels of a living animal, and is left standing at rest in a suitable vessel, it very soon separates, as is well known, into a thin serous liquid, and a clot which floats upon its surface. The clear liquid is, however, not the same thing as the transparent plasma in which the white and red corpuscles are orginally contained. It is that blood-plasma, deprived of its fibrin, or most adhesive part. The fibrin separates from the clear liquid as a mass of interwoven threads, and, as it does so, entangles the corpuscles in its meshes. The clot consequently is the corpuscles and fibrin mingled together.

The oily principles of the food, which are taken up in such abundance from the villi of the intestines by the lacteal vessels, are carried on into the blood and mingled with the general stream. But they rarely accumulate in it in any large quantity, on account of being immediately turned to account in various active processes that are in progress in the system, and especially in those which are concerned with the production of muscular movement, and with the maintenance of the warmth of the body. They rarely amount to as much as a half per cent. of the liquid plasma. They are rapidly seized upon by the oxygen carried in the red corpuscles of the blood, and are by its agency consumed, being turned into carbonic acid and water by a kind of slow burning. Small portions of them are applied to constructive work; but by far the greater part, after having been in some way ultimately mingled with the organized structure, are used for the maintenance of the heat of the body.* In average health, the blood of the living animal is kept by this agency at a steady temperature of 98°, which appears to be the most favourable one for the carrying on of its multifold operations. Whenever at any time the oily ingredients become too abundant in the blood, they are forthwith drawn out from the channels of the circulation, and stored away in convenient reservoirs as fat. They are then taken back into the blood out of these store reservoirs if at any time too little of the combustible fuel is supplied directly from the food for the maintenance of the proper degree of warmth. It appears that oil is also to some extent made for heating purposes in the animal economy, out of other principles, by a destructive change in their composition.

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* There is some doubt whether the oxidation of these combustible principles ever takes place freely in the blood. (See Lecture IX.)

LECTURE V.

The Liver, and Secreting Organs.

It is a remarkable circumstance that sugar is only contained in the blood in very minute quantities, notwithstanding the very large abundance of it that is supplied from the digestion of farinaceous food, and introduced through the absorbing vessels of the alimentary canal. There is, of course, a special reason for this, and it is worthy of careful attention on account of the part which the arrangement plays in the operations of the living organization. Starch, it will be remembered, is a product of vegetable elaboration, which is rendered insoluble in liquid menstrua, in order that it may serve the purpose of a fixed store, to be drawn upon as need requires; and which is converted into sugar in the process of digestion, in order that it may be capable of transport as a liquid through the absorbing pores of the digestive tract. But this soluble sugar is again turned back into an insoluble condition, very much resembling that of starch, when it has been introduced into the inner chambers of the animal body. All the saccharine portions of the digested or digesting food are drawn into the looped meshes of the delicate blood-vessels which have been described as distributed upon the walls of the digestive canal. But the entire series of these collecting loops are finally united together to form one large vessel that carries the blood they have gathered from the digestive cavity to the liver. By the action of the transmuting powers of the liver, the sugar is there converted into a substance known as glycogen, which is properly a kind of animal starch. Its chemical composition is very nearly the same with that of the starch formed by the plants, with the exception, perhaps, that there are three times as many of the atoms of each different elementary ingredient in each of its molecules. There appear to be in each eighteen atoms of carbon, thirty atoms of hydrogen, and fifteen atoms of oxygen.

Symbol expressing the chemical composition of a molecule of glycogen, $H^{30}O^{15}C^{18}$.

This gives, it will be observed, exactly the same proportional amount of three several ingredients as is present in the smaller molecules of vegetable starch. The glycogen thus formed is stored in the liver, so that its vesicles and chambers are at all times densely charged with the product. But the abundant glycogenous store there collected is again gradually and slowly turned back into sugar, and in that state re-issued to the blood as it passes on from the liver to the heart, to be forwarded thence, by its pumping action, to all parts of the frame. The name of this substance is intended to imply its readiness for conversion back into sugar. It means simply the "generator of sugar."* The sugar thus provided, and thus regularly issued to the blood, in carefully apportioned quantities, is then used both for building and warming purposes. It is burned up as a fuel, after it has been in some way attached to the living organization, and so turned into water and carbonic acid with the evolution of heat. It is in this very ingenious and admirable way that the copious amylaceous ingredients of the food are turned to account as heat-producing fuel, without at any time accumulating in the blood in sufficient quantity to cause derangement in the delicate balance of its composition. The singular resemblance of this procedure to the one which is adopted in the plant will be at once perceived. In the plant, soluble sugar is converted into insoluble starch, that it may be stored in the seed, and be then reissued as soluble sugar, in carefully-regulated proportions, as that is required for the purposes of construction and growth. In the animal, insoluble starch is converted into soluble sugar, that it may get washed through the fine pores of the digestive membrane into the blood-vessels. It is then reconverted into insoluble, starch-like glycogen, that it may be stored within the liver, and it is subsequently reissued from the liver in the form of soluble sugar, in carefully regulated quantities, as it is required by the blood.

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* It is derived from the Greek words *glucos*, sweet, and *gennao*, to produce.

The albuminous principles of the digested food are treated in the system very much in the same way as the unnitrogenized product just spoken of. The albumen, after it has been broken up and dissolved by digestion, is carried with the sugar in large quantities to the liver, and is there split up into two parts, of which the one is appropriated to the fabrication of glycogen, whilst the other is destined to be ultimately eliminated from the blood, by the action of the kidneys, after having first performed some intermediate structural service.* As a general rule, glycogen is most copiously stored in the liver when a superabundance of farinaceous and saccharine food is consumed. The great use of the liver, indeed, seems to be to fabricate a fixed store of nourishing and warming material out of the starch, sugar, and albumen of the food, and then to reissue it to the onward flowing blood in never-failing, although regularly measured, streams, for the vital needs of the system.

The fibrinous, glutinous, and albuminous, or nitrogen-containing, ingredients of the food, as has been briefly stated before, undergo in the process of digestion a transformation of a somewhat similar character to that which is effected with sugar and glycogen. They are transmuted into a more soluble state, in order that they may be the more readily introduced into the channels and vessels of the absorbing villi, and are then turned back again into albumen after they have been so received. In this more soluble state, the product is technically known as "peptone." There are slightly different forms of this principle, according to the precise nature of the food from which it is derived. But in all, peptone is still merely a highly soluble state of the albuminous material, prepared by the action of digestion to facilitate its introduction into the channels of the system. Peptoncs are taken with the sugar to the liver, and are there with it subjected to a rearranging operation.

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* It is now well understood that albumen is decomposed in the liver into non-nitrogenized glycogen and nitrogenized urea.

The oleaginous ingredients of the food are also, to some extent, dealt with by the liver, although they do not appear to take any direct part in the fabrication of glycogen. All that seems to happen with fat, which is introduced ready formed as an integral part of the food, is that the albuminous membranes, investing and shutting in the oil globules, are broken up and digested, and the globules are so left free to turn themselves into the chyle, or lacteal emulsion, which is sucked into the chyle channels of the villous processes. The oleaginous globules are then transferred directly to the blood, and are there applied as a kind of supplementary reenforcement of the stores of glycogen and albuminous material furnished by the liver. It is almost certain, however, that, in addition to the fat of the food, other fat is in some way generated in the chambers of the body, out of the saccharine and albuminous materials. Both the oil and the glycogen are transferred to the living structures, and afterwards burned with the production of warmth. The chief difference in regard to them seems to be that, in burning, the material derived from the glycogen is converted principally into carbonic acid, whilst that derived from the oil is transformed into carbonic acid and water, on account of the larger proportional quantity of hydrogen which oil contains.

The formation of glycogen in the liver is an apt illustration of what is termed the process of "secretion." The glycogen is secreted, or separated from, the blood.* The liver is, consequently, an organ, or instrument, constructed for secretion. It is a very large structure on account of the important function which it has to perform. Besides glycogen it secretes bile, which is temporarily stored in a receptacle known as the gall-bladder, and which is thence returned into the alimentary canal, to give further assistance there in the digestion of the food; the bile, however, is principally formed from the exhausted nitrogenous substances, which have accomplished their task in the construction of vital organs, and which require therefore to be removed out of the blood and dismissed from the system, and not from the fresh food, as glycogen is. The bile is principally waste matter; but, before it is finally ejected, it is turned to good practical account, by being made to contribute to the introduction of fresh supplies of food. Thus it neutralizes the free acid of the gastric juice as soon as the digesting pulp is mingled with it in the alimentary canal. It removes out of the way the ferment which was mingled with the acid to bring about the solution of starch, and so prevents it from interfering with another ferment, furnished in the pancreatic juice, and adapted to perform its work in the presence of an alkali, instead of in cooperation with an acid. And it prepares the absorbent membranes of the villi of the alimentary canal, to appropriate and receive the emulsified fats, which reach them in the form of chyle.*

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* The word secretion is derived from the Latin *secretus*, severed or *separated.*

The liver is the largest secreting organ of the body. In a fully-grown human being it weighs nearly four pounds. Its substance is almost entirely made up of minute vesicles, scarcely the thousandth part of an inch in diameter, arranged in the form of clustered lobes, and packed densely into the meshes of the blood-vessels and bile ducts. The great vessel, which gathers the blood from the long stretch of the intestinal canal and from some of the neighbouring parts, enters the liver as a large trunk, which is called the portal † vein, because it in this way enters the liver as if by a gate. This trunk is divided out into a network of hair-fine or capillary vessels, which are distributed throughout the organ. They are broken up, however, into a great number of separate clusters to constitute what are designated the lobules of the liver. It is in these lobules that the secreting vesicles are packed amid the minute branches of the blood-vessels. The vessels in each cluster, or lobule, converge to a central receiving channel, which passes out from the lobule as a vein, and ultimately conveys the blood on to the main venous trunk that terminates in the heart.

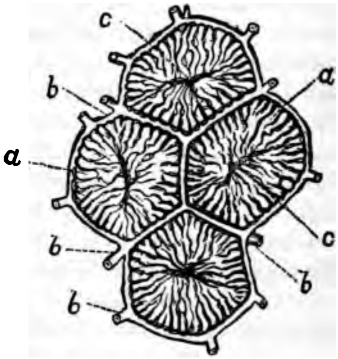

Fig. 17.—Showing the arrangement of the small branching veins in the lobules of the liver (*a*, *a*) which run from (*b*, *b*, *b*) the incoming branches of the portal vein that carry the blood from the intestines to the liver—to (*c*, *c*, *c*) the commencements of the hepatic vein, that conveys the blood on from the liver to the heart.

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* Oily matters which are repelled by animal membrane in an ordinary state, readily filter through it after it has been soaked in bile.

† "Portal" vein, from the Latin word *porta*, a gate.

Another and quite distinct network of fine vessels is interwoven with the branching blood-vessels, to receive the bile, which is drawn out from them by the vesicles. As the blood is flushed on in a continued stream through the minutely-divided blood-vessels of the lobules, the ingredients of the bile are drawn out of it by the vesicles, and poured into these separate channels. This is the essential part of the act of secretion, or separation. The bile is then gathered up from these receiving ducts into larger and larger tubes, which finally discharge their contents into the gall-bladder, a reservoir of considerable capacity. From this the bile is passed through another vessel, known as the common bile-duct, and then discharged into the alimentary canal, to be there mingled, as has been already described, with the mass of the digesting food. The glycogen is taken out of the blood by a similar apparatus of secreting vesicles, but it is retained and stored apart in the interior chambers and cavities of the liver, to be thence gradually issued, as it is required, not to the gall-ducts, which would pass it on to the digestive cavity with the bile, but to the hepatic veins which run on to the heart. The great mass of the blood is thus deprived of the ingredients of bile and glycogen as it passes through the liver, and is sent on, to that extent refined and purified, to feed the stream which is distributed from the heart for the general uses of the frame. The liver is thus both an elaborating, or perfecting, and a purifying organ. Besides separating the waste refuse which chiefly constitutes the bile, it forms the fixed store of glycogen, and also produces some subtle rearrangement of their ingredients in the molecules of the blood, which renders them more fit for the work to which they are finally applied.

It can, therefore, be readily understood why the liver is so large an organ. It completes the preparation of the food for its great work of sustaining the movements and functions of animal life. It is in this sense the effective source of vital strength and power, as is in some measure indicated by the fact that the blood which issues from the liver by the hepatic vein, possesses a higher temperature than any other parts of the living fabric. The organ is of such vast importance, that it contains within itself about one-quarter of the blood at any time within the body. It has also a double supply of blood. It receives arterial blood for its own sustenance and support from the hepatic artery, and it receives venous blood, the material upon which it has to operate in fabricating bile and glycogen, from the portal vein. Sugar and peptones are stopped by the liver, on their way from the alimentary canal to the general circulation, in order to be turned into glycogen and urea. It has hence been proposed by one high physiological authority * to designate the liver a "sugar-destroying" organ. If at any time this proper office of the liver be inefficiently performed, and the sugar be not duly arrested and converted into the store of passive glycogen, the excess of it appears in the blood, and in other parts of the living frame, where it ought not to be. In the disorder known as diabetes, this is particularly the case, and free sugar is discharged in large quantities by the kidneys. It is now well understood that this grave disease very commonly originates in the failure of the liver to accomplish its proper work, and the disease is often successfully healed by withdrawing all kinds of starch and sugar from the food, in order that the liver may have no sugar to destroy, and, in this way, be relieved from the strain of work which is too much for it in its deranged state.

It is not thoroughly understood how sugar is changed into glycogen in the liver; but it appears to have been ascertained that the transformation is brought about by the

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* Tscherinow speaks of the liver as being glycophthiric, that is, sugar destroying.

production in the vesicles of that organ, of a small quantity of a very active ferment, which has the power of accomplishing the conversion. At any rate, the two great functions, which are now attributed to the liver by physiologists, over and above its more obvious office of forming bile, are first to make glycogen from the sugar and peptones supplied from the alimentary canal, and store it up until required for use; and, secondly, to give back to the body during fasting the nourishment it has stored up during digestion, by reconverting the glycogen into sugar.

The liver is correctly spoken of as the largest of the secreting organs contained in the body of the living animal. But is only one of a somewhat numerous group of structures provided for the same work of separation, or secretion.

In all of these a similar type of construction is adopted. Blood vessels ramify out into a network of capillaries, and then collect into large common channels that issue from the network; and vesicles are packed in amid the meshes of the vascular reticulation, with a system of separate ducts to receive the product which they draw out of the blood. Whenever any particular liquid has to be prepared for some specific service, this plan is pursued. The liquid is drawn by the clustering vesicles out of the blood, as it flushes through the capillaries. The saliva required to effect the softening and solution of the farinaceous parts of the food, is prepared by the secreting clusters of vesicles which constitute what are known as the salvary glands. The stomach itself is a vast, hollow, secreting gland, its thick walls being permeated by the vesicles and plexus of blood vessels, which are required for its secreting operations: the liquid it separates from the blood by their help, is the gastric juice that is poured out into the cavity of the organ from a myriad of little follicles, or pits. The pancreas is a secreting gland which separates a juice that deals with both the farinaceous and the oleaginous principles of the food, in the interior of the alimentary canal. The spleen is a gland which has no channels of outflow. It is made up of lobed clusters of vesicles, and finely-meshed capillary blood-vessels; and it appears simply to produce some change in the composition of the blood as it passes through the capillaries, tending to its more perfect elaboration. It is thus a secreting organ without any outflow, for the product of its action, which therefore passes on in the general stream of the blood, instead of being collected from it into some separate channel, or reservoir. In all these instances, the organs are, so to speak, manufactories for the fabrication of products that are required for some special service in the living economy. The liver, it has been seen, is a secreting organ of a compound nature, in which certain products are elaborated, at the same time that a vast mass of waste material is drawn out of the blood. The skin is a secreting organ, spread over the entire external surface of the body, and pierced with a myriad of pores, through which the material, separated by it from the blood, is perspired, or exhaled into the air. The kidneys are secreting organs, designed for a special and most important work of purification, and will have to be more particularly dealt with in a subsequent lecture. They take from the blood the waste materials, resulting from the wear and tear of the nitrogen-containing ingredients of the living organization, and wash them away as urea suspended in water. The lungs are excreting organs which separate waste substance from the blood, by means of a widely-spread net-work of capillary vessels, and which discharge it into the outer air as impalpable vapours and exhalations.

The structure of secreting glands was first carefully investigated by Professor Malpighi, of Bologna, towards the end of the seventeenth century. He was aware that the secretions were poured out from the blood in the fine capillary vessels of these glands. But he thought that the process was merely one of filtering. He conceived that the glands were something of the nature of sieves, and that the material separated in them from the blood depended very much upon the fineness or coarseness of the pores through which the liquids had to pass. This view was pretty generally held until, in 1830, the German physiologist, Johannes Müller, published a very remarkable treatise on secreting glands. In this he for the first time taught that the act of secretion was due to living matter contained within the glands. The Scotch physiologist, John Goodsir, confirmed this view, and attributed the process to the influence of the vesicles, which are packed away in the glands amidst the branching blood-vessels and ducts, and which are themselves elaborately organized, living structures. He pointed out that the special secretions make their appearance just within the interiors of these vesicles, and are discharged from them into the ducts which are provided for their reception and removal. He maintained that the difference of the secretion in each case is due to the difference of the vesicles which are operative in each kind of gland, and that these vesicles are organized in the most exquisitely perfect way for the particular work they have to perform. Certain liquid materials of the blood are exuded through the filmy walls of the fine capillary blood-vessels into the intervascular spaces of the gland, as a kind of lymph, and this lymph is then absorbed by the vesicles and used as the raw material of their elaborating work. Fine nerves are supplied to the capillary blood-vessels of the glands, and exert some influence over the process of secretion, by the power which they possess of dilating and contracting the channels of the vessels. But the structures that are essential in every form of perfectly developed secreting gland, are the blood-vessels which supply the blood, and living vesicles which act upon that blood, and the ducts which receive and utilize the products of that action.

In the case of the three great secreting glands that are most immediately concerned with the process of digestion, namely, the salivary glands, the gastric follicles, and the pancreas, the power of the secretion is mainly due to a particular substance termed a ferment, which is generated by the vital action of the vesicles. A ferment, as will be understood, is a substance of somewhat complex composition, which is capable of setting up a progressive change of molecular constitution in a considerable number of other substances also of complex composition, when added to them in comparatively minute quantities, as occurs when yeast is mixed with dough or with sweet-wort. The change produced in the larger mass is that which is familiarly known as fermentation, on account of its being invariably accompanied by the escape of carbonic acid gas with a kind of bubbling, or boiling. There are two distinct forms of ferments known to physiologists: the organized, and the unorganized,—technically called also "zymogens," or the generators of fermentation; and "enzymes," or contained ferments, so designated because, for the most part, they result from the transformation, or decomposition, set up by the vital action of organized ferments, or zymogens, and are at first stored within them. Enzymes, or unorganized ferments, are thus commonly fabricated within the interior of the vesicles of secreting glands acting as zymogens, and may be extracted from them. It is upon these unorganized ferments, thus generated, that the dissolving and transforming powers of the digestive juices depend.

Thus, within the living vesicles of the salivary gland, an unorganized ferment is fabricated by their vital agency, which is capable of digesting starch and converting it into sugar. Within the vesicles of the glandular follicles of the stomach, a ferment is constructed which, with the co-operating agency of a free acid, is capable of digesting nitrogenized food-substance into peptones.

Within the vesicles of the pancreas, three ferments are generated, which are competent to take up and complete the work that has been left unfinished by the salivary glands and the stomach: the one converting starch into sugar, and being capable of doing so in the presence of a free alkali, which is required in the lower part of the alimentary canal for the operations upon fat; the second changing nitrogenized substances into peptones; and the third transforming fats and oils into an emulsion. The fat-decomposing ferment of the pancreatic juice acts only after the neutralization of the acid.

The pancreas, which is provided for completing the already half-accomplished digestion, and for dealing, in the lower part of the alimentary canal, with all the several classes of food-constituents, has three distinct kinds of vesicles contained within itself: one for furnishing the ferment that transforms the starch, one for supplying that which transmutes the nitrogenized substances, and one for the production of the ferment that decomposes and changes fat into chyle.*

The stomach has two kinds of secreting vesicles: one for the preparation of the ferment, and one for the production of the acid. The salivary glands have also two kinds: one for the production of the ferment, and one for the formation of mucus, which lubricates the mouth and facilitates the movements required for vocal articulation and for swallowing.

Each one of these different kinds of vesicles is so distinct in its aspect and structure, that it can be at once recognized by the anatomist. One of the most remarkable of the conditions found in this complicated process, is that the acid which is secreted in the stomach, by one of these varieties of vesicles, is the unorganized, and in its concentrated state corrosive, agent known to the chemist as hydrochloric acid. This hydrochloric acid is produced in the vital economy of the body by a direct chemical decomposition of some of the saline ingredients contained in the blood. The vesicles draw these ingredients in solution out of the blood, and then loosen and rearrange their elementary constituents and fabricate the acid out of them, which is immediately afterwards mingled with the other secretions from the glands of the stomach, so that it remains from the first in a very dilute state.

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* The starch-dissolving ferment, in saliva and gastric juice, is called diastase; the proteid dissolving ferment of gastric juice is termed pepsin; and the proteid dissolving ferment of the pancreatic juice is distinguished as trypsin.

LECTURE VI.

The Circulation of the Blood.

THE various secreting organs are supplied, it will be remembered, with the blood, which their separating powers are to operate upon, by means of branch vessels thrown off from the great trunk blood-vessels; some from the arterial trunks which forward the blood from the heart, as in the case of the salivary glands and secreting follicles of the stomach; and some from the venous trunks which carry the blood back to the heart, as in the case of the liver. In all these instances, it is a portion only of the great circulating stream that is diverted to the secreting apparatus. Thus it is about a fourth part of the entire volume of the blood which is sent to the liver during each act of circulation. But there is one secreting organ marked out from all the rest by the circumstance that the entire volume of the blood is passed continuously through it. This is the organ which is known as the breathing apparatus, or lungs. It is called the breathing apparatus, because it is breath, or an air-like vapour which is separated in it from the blood; and it is this arrangement of passing all the blood through it, immediately and in rapid succession, which has made necessary that reduplication of the heart which has been already incidentally alluded to. One-half of the heart is engaged in distributing the blood to the lungs, whilst the other half *is occupied with* its distribution to all other parts of the system. Both the halves act at the same instant, and it therefore seems as if there were only a single contraction, or stroke of the pumping organ. But, as an actual fact, it is a portion only of the blood which is thrown out to the lungs at each stroke, and two strokes are therefore required to deal with the two separate parts of the circulating liquid.

The heart is properly divided into a right and a left department or cavity. Both cavities are alike in the fact that they have a receiving and a distributing chamber, known technically as the auricle and ventricle, which are only separated from each other by a trap-door, or valve, hung so that it allows the stream to flow in but one direction—that is, from the receiving chamber into the distributing one. The left side of the heart deals with the blood which is issued to the frame in general, and the right side with that which is destined for the lungs. There is also this further important condition in the arrangement. The blood which is issued from the left chamber of the heart, is returned to the opposite chamber on the right; and the blood which is issued from the right side, is returned to the chamber on the left. The movement of the blood thus describes a kind of figure of 8. The blood from the left issuing-chamber is injected into the general system—the head, body, and limbs—and is returned to the right chamber, to be thence injected into the lungs, and returned from the lungs to the left chamber, for issue in due time as before. This somewhat complicated arrangement may be best explained by the use of a diagramatic representation, in which the double distribution and figure of 8 circulation may be seen at a glance.

The passage taken by the blood from the right ventricle through the lungs is a very much shorter course than the one which has to be followed through the manifold structures that constitute the head, body, and limbs; and so also, the space which is afforded for its reception in the lungs is of much narrower dimensions than the space which is furnished by the rest of the body. The lungs-half of the

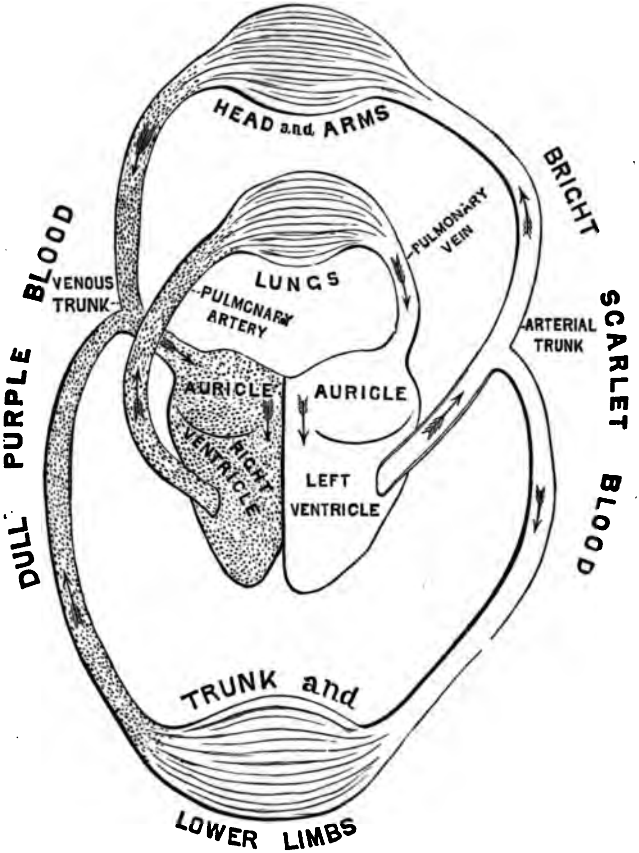

Fig. 18.—Diagramatic sketch, showing the double circulation and figure-of-8-like course taken by the blood; from left ventricle to head, body, and limbs, right auricle and ventricle, lungs, and finally to left auricle, in completion of the double circuit.

blood, nevertheless, has to get through its journey in the same time as the half which belongs to the side of the general circulation. If it did not do so, there would obviously be derangement of the even flow of the stream. It would be driven into a heap and accumulate in undue preponderance, where it was pressed into the narrower space. This is obviated by the passage through the lungs being arranged as a more free and open one, so that the blood there pursues its way at higher speed. The right side of the heart, in consequence, has an easier task upon its hands, although it issues the same volume of blood as the left. It is, therefore, not made so bulky and strong as the left. It is probable that the right side of the heart does not need to exert more than a fourth part of the force, to get its half of the blood through the capillary vessels of the lungs, that the left side has to exert to get its half through the capillary vessels of the rest of the body.

When the blood is thrown from the right ventricle of the heart, it enters a large vessel which runs directly to the lungs—the soft, spongy structures that are packed in the chest on each side of, and close to, the heart—and there divides into two branches, proceeding the one to the right, and the other to the left, side of the chest. But both of these primary trunks then further subdivide into smaller and smaller ramifications, until they at length end in the usual delicate network of capillary vessels, in this case scattered through the lungs.

These terminal vessels are, in the case of the lungs, so minute, that as many as five thousand of them might be laid side by side within the length of an inch, and the network is so close and fine that its meshes are scarcely wider than the vessels themselves. The capillaries of the network are ultimately gathered up to constitute enlarging tubes, which receive the blood, and carry it on, getting constantly more capacious as they go, until they at length end in one main channel of outflow, which empties itself into the left auricle of the heart. So long, therefore, as the right ventricle dilates and contracts, so as to maintain its pumping operations, the blood is flushed in a never-ceasing stream through the substance of the lungs. But the blood is materially changed in its character as it thus flows through the pulmonary plexus of capillary vessels. It is of a dark purple colour when it enters the network, and it is of a bright scarlet hue when it leaves those intermeshed channels. It is dull venous blood which goes in, and bright arterial blood which passes out. What has next, therefore, to be described, is the way in which this remarkable change is brought about within the pulmonary structure, and the purpose that is answered by the change. The first step to the due comprehension of the arrangement is to understand that there are air-vessels, as well as blood-vessels, in the complicated structure of the lungs, and that the two are brought into a very close and intimate connection, each with each, which enables the air and the blood to mingle and to act the one upon the other.

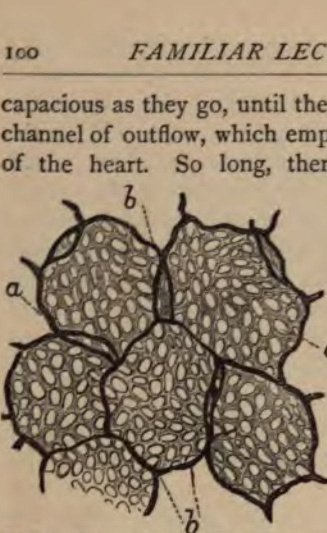

Fig. 19.—Network of capillary blood-vessels (a, a) spread upon the air-cells of the lungs (b, b).

The air-vessels of the lungs begin in the cavity of the mouth. Immediately behind the root of the tongue, and at the top of the throat, there is the opening to a great, cartilage-stiffened tube, which is designated the windpipe, because it carries wind, or moving air. The windpipe passes down through the neck, and then forks out to each side of the chest. One branch of the fork goes to the right side of the lungs, and the other to the left.

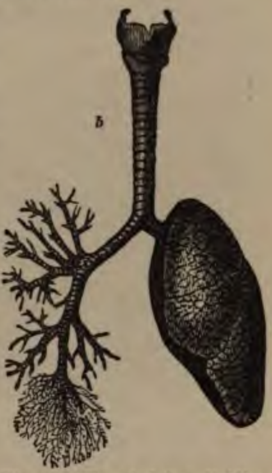

Fig. 20.—The windpipe, dividing into bronchial tubes, and distributing itself to the air-chambers of the lungs.

Each branch of the windpipe then gets the name of a bronchial tube,* and goes on branching and dividing until it finally ends in an enormous number of round, blind extremities, or bulbous recesses. These bulbous chambers are cavities designed to be inflated with air from the mouth. They are technically known as the air-cells, or air-chambers, of the lungs. In their ordinary and natural state they are full of air.

These air-chambers of the lungs are themselves so small that something like a hundred of them could be ranged side by side within the space of an inch. The ends of the bronchial tubes are clustered round with these bulbous cavities, which have walls of the utmost fineness and delicacy. The chambers, indeed, consist altogether of films of the thinnest conceivable tissue. The air-tubes are strengthened and stiffened by walls of gristle, so that they may be kept constantly open to the passage of air. But at their dilated, bulb-like ends, the thick gristle disappears, and there remains only a thin permeable membrane, capable of being as readily penetrated by vapours and moisture as bibulous paper is. Upon these permeable walls it is that the capillary blood-vessels are distributed.

Thus, as the blood is flushed through the capillary network of vessels, it is brought into the closest possible connection with the air. The blood and the air are for the instant only separated from each other by the thin films of the air-cells and capillary blood-vessels. Consequently, the blood and the air are free to communicate with each other through the pores of these membranes. Vapours from the blood are steamed out into the air lurking in the bulbous cavities of the air-cells, and particles of the air pass in to the channels of the capillaries, and mingle with the blood.

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* From the Greek word *brongchos*, the windpipe.

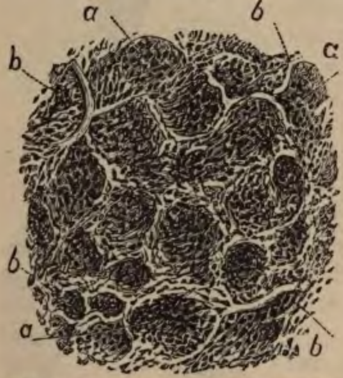

Fig. 21.—Interior of air-chambers of human lung (*a*, *a*) covered with capillary blood-vessels (*b*, *b*); largely magnified.

But the air in these air-chambers is in motion as well as the blood; not however in a continuous stream, but in alternate puffs, out and in. It is this movement of the air in the air-cells of the lungs which is provided for by the out-and-in play of the walls of the chest. The air is alternately drawn into, and driven out from, these cavities by the movements of breathing. When the chest is expanded, air flows in, and when the chest is contracted, air is driven out. It is this which constitutes the essential part of breathing. The expansion and contraction are managed by the movable ribs, or bony basket-work, which form the outer walls of the chest, by an arched muscular floor which is capable of rising and falling as the breath is thrown out and drawn in, and by the natural elasticity of the pulmonary tissue. The cavity of the chest is enlarged by the action of the muscular fibres, and is then contracted by the elastic resiliency of the textures returning to their original condition after they have been stretched by the muscles. But the air, which is thrown out from the lungs in the act of respiration, is different from that which is, in the first instance, drawn in. It is subjected to a certain measure of change whilst it remains in the air-cells in the close neighbourhood of the coursing blood. When it is driven out from the chest it is warm, instead of being cold, and moist instead of dry. The moisture may be seen, indeed, issuing from the mouth as a cloud of steam, on a cold frosty day. The expired air is also loaded with the heavy vapour of carbonic acid. At the same time, it is less abundantly charged with oxygen gas, the more active constituent of air. All this change is virtually effected by the stream of the coursing blood. The warmth, the moisture, and the heavy carbonic acid come out of the blood, and the oxygen lost by the air at the same time goes into the blood. Eight grains in every thirty-six of the air that goes into the lungs is pure oxygen. But there are less than three grains of oxygen in the same quantity of air when it is exhaled. The air, returned from the chest, contains four per cent. more carbonic acid than the air which goes in, and rather more than four per cent. less oxygen. Pure air contains 416 parts of oxygen and one part of carbonic acid in every 2000 parts. The air, which is expired with the breath, contains 80 parts of carbonic acid, and only 32 parts of oxygen in every 2000 parts. The aqueous vapour, which is expired with the breath, amounts commonly to as much in every twenty-four hours, as would form a pint of liquid water when caught and condensed. The temperature of the breath, which comes out from the mouth, is about 93 degrees of Fahrenheit's thermometric scale.

It will now therefore be understood whence it is that the red compound, lodged in the cavernous pores of the blood-corpuscle, gets the high charge of oxygen which is loosely associated with its porous mass. The red-corpuscle of the blood is essentially a carrier of oxygen to all the internal recesses of the frame, and it gets the oxygen it carries from the air-chambers of the lungs. The change in the colour of the blood, which occurs in the lungs, has also to be traced to the same source. The hæmoglobin of the corpuscle, so long as it has only its low charge of oxygen is of a dull purple colour. But this purple tint is changed into bright scarlet when it has received its full charge of oxygen.*

The lungs are of considerable size. They are not very far inferior to the liver in their dimensions. In a full-grown man they weigh nearly three pounds. When fully inflated, the lungs can contain, in all their air-tubes and cells, as much as 334 cubic inches of air. But of this not more than 20 cubic inches, or about two-thirds of a pint, are changed with each act of inspiration. Scarcely more than the sixteenth part of the entire air-charge of the lungs is changed with each act of breathing. It requires, therefore, sixteen breathings in succession to change the entire volume of air. But, as the air that is breathed is deprived of so large a portion of its oxygen, and receives so large a surcharge of carbonic acid, it is spoiled by the act for all purposes of animated life. A full-grown man, breathing sixteen or seventeen times in the minute, spoils something more than 300 cubic inches, or one gallon of air, in that time, and not less than 250 cubic feet in twenty-four hours. If a man could be closely shut up in a square room, measuring seven feet across in all directions, and could be made to breathe in that closed space for twenty-four hours, the entire volume of air which it contained would be changed at the end of that time into just the condition of air expired from the lungs. But, as a matter of fact, no human being could live for twenty-four hours in such circumstances. He would die long before, suffocated by excessive accumulation of carbonic acid and deficiency of oxygen.

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* Hæmoglobin is of a dull purple, and oxy-hæmoglobin of a bright scarlet colour.

The red corpuscle of the blood, when it is driven in the general current of circulation through the network of the capillaries of the lungs, draws oxygen to itself out of the air-cells as it passes along the fine filmy walls surrounding their bulbous cavities. Its hæmoglobin attracts the oxygen until it has acquired as large a charge as it can retain. It then hurries on with its burthen to the left ventricle of the heart, and is thence pumped out to some particular part of the living system, still carrying with it the oxygen. But there the oxygen suddenly leaves the corpuscle which has had it in charge, and attaches itself to some structure in the frame for which it has a more eager affinity. This operation, however, is one which exerts a most important influence over the receiving substance. By the touch of the oxygen, that substance is degraded, or decomposed in its own structural integrity, with the production of warmth as one incident of the change, the decomposition being of the nature of a slow burning. Carbonic acid and water are produced by the union of the oxygen with carbon and hydrogen, and as this carbon and hydrogen are removed from the substance, the rest falls into destructive decomposition and decay; or is at least degraded into some lower form of chemical existence, so as to be advanced a material stage towards such decomposition and decay. The progressive elaboration of the ingredients of the food, as they pass forward into the blood, and become integral parts of the animated structure, is in reality the preparation of the substance to undergo this destructive transmutation by oxygen. The crude albumen, for instance, which is introduced by the act of digestion, is hardly obnoxious to the influence of oxygen. But once it has assumed the state of living albumen, either in the blood, or in the structure of organs, it is at once prone to be attacked by the arch destroyer's degrading power. It is said that albumen is alive in the animal body when it is once able to "breathe oxygen;" that is, to be decomposed and destroyed by its touch with the evolution of heat. The distribution of oxygen from the air-cells of the lungs, by the intermediate instrumentality of the red corpuscles of the blood, in reality "blows up," so to speak, the flames of life. It is the determining cause of pretty well all the activities that animal life presents. The carbonic acid, which is generated by the union of oxygen with the carbon of the decomposed substance, is absorbed into the plasma, or liquid, of the blood, and is by it carried in due course to the lungs, to be exhaled into the air-cells. This, therefore, is the source of the heavy charge of carbonic acid which is carried out by the breath.

The various actions of the living economy of the animal are all intimately connected with a process of slow combustion, or burning of the various structures of the frame, under the touch of the oxygen which is borne to them by the red corpuscles in the streams of the circulating blood. The various organic principles elaborated in the food, in all probability undergo a series of progressive changes, after they have been introduced into the system, of increasing complexity, before they are severally built into some organized part of the frame; and then are in the same way passed backwards through a series of progressively diminishing complexity, before they are finally loosened and resolved back into their primary elements. Thus the glutinous product of plant-organization becomes peptone, albumen, blood plasma, and in the end, perhaps, muscle, or brain; and the muscle, or brain, is then gradually reduced back, under the degrading agency of oxygen, supplied by the omnipresent blood-corpuscle, into simpler and simpler forms, such as the various ingredients of bile, urea, and the like, until they are finally ejected from the system as carbonic acid and ammonia.

This progressive transformation, first in the ascending, and then in the descending grade, is distinguished by the physiological science of most recent date as "metabolism;" and the various compounds of the body, which are most prone to pass through this ordeal or transformation, are called the metabolic* constituents of the organization. They are essential beyond all other principles to the maintenance of vital action, because it is out of their degradation to the simpler forms of composition, and their resolution into ultimate elements, that animal warmth, and the forces of the various organs are obtained. But, in all probability, in every case in which vital force is thus derived from a complex association of the material elements of the frame, it is indispensable that the complex association shall have first been built into, or very intimately connected with, the actual living organization, and in that sense have been endowed for the time with a kind of vitality of its own. In some instances, and most essentially in that of muscular fibre and nerve substance, two quite distinct forms of living structure are associated together, of which the one is concerned in the maintenance of the structure of the part, whilst the other, by virtue of a more rapid and more energetic transformation, is expended in accomplishing the work. In every case, however, the oxygen is almost certainly given up by the blood corpuscle to the tissue for incorporation with its substance, and then forms in that tissue a material which decomposes with a kind of explosive discharge whenever any vital effort is made. The explosion, or vital effort, is in every instance of necessity accompanied by destruction of tissue, the results, or *débris*, of which are carried away in the forward flowing streams of the blood, to be ultimately discharged from it through some one or other of the outlets of excretion.

The blood, which is issued from the left side of the heart, is bright scarlet, or arterial blood, because it has just arrived from the lungs, where the accumulation of carbonic acid has been thrown off, and a fresh charge of the vivifying oxygen been received by the red corpuscles. The blood, which is issued from the right side of the heart, is dark purple blood, because it is blood which has been deprived of its vivifying oxygen, and which is on its way to seek a fresh charge in the lungs. The right side of the heart thus receives into its auricle dark purple and exhausted blood from the general textures of the body, and issues the same from its ventricle to the lungs; whilst the left side of the heart receives from the lungs into its auricle the bright scarlet renovated blood, and issues that renovated blood to all other parts of the body. The figure-of-eight circulation is thus divided into a dark purple and a bright scarlet half; the dark purple half being blood on its way to the lungs, and the bright scarlet half, blood on its way to the other textures of the body where its business is simultaneously to stir up and support the various vital activities.* The arterial trunk from the right side of the heart thus deals with dark purple, or venous blood, although it is essentially an artery; and the arterial trunk of the left side deals with bright scarlet, that is, with true arterial, or renovated and revivifying blood.

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* From the Greek word, *metabolos*, changeable.

It must here again be observed that, in this process of aerial purification and renovation of the blood, it is water, furnished by the drink, that is the chief agent in the mechanical work of transport. The carrying is all done by water; the oxygen is washed from the lungs to the remotest recesses of the living frame; and the carbonic acid and other products of the wear and tear of the structures are washed back to the outlets, from which they can be discharged into the air, or into external space. The introduction of oxygen to the innermost recesses of the frame to fan the fires of life, and the removal of the waste resulting from combustive and degrading operations, are alike provided for by the mobile powers and ready fluency of water.

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* This peculiarity of the distribution of the effete purple and the fresh scarlet blood, will be more easily apprehended by a careful and attentive study of the diagram given at page 98.

LECTURE VII.

The Structure and Functions of Muscle, Nerve and Brain.

It has been pertinently and happily remarked, that the muscles and nerves are the master structures in the organization of animal bodies, to which all the rest minister as servants. This is a correct statement of the fact. The body of the animal is obviously planned with a view to the accomplishment of the two great purposes of animal life; movement from place to place, and the establishment of a conscious relation with the objects of the external world. These purposes are carried out by means of the muscles and nerve apparatus. In both these, so unlike parts of the material frame, although the structures themselves are of a specific character, a certain amount of uniformity of plan is followed.

The movement of the animal body from place to place is accomplished by means of jointed levers, termed limbs, worked by contracting and expanding fibrous cords, called muscles. The muscles are composed of bundles of fibres bound up in sheaths, and in that state they constitute what is known as the flesh of the animal. If a large muscle is cut across in a dead animal, this arrangement is at once brought under notice. The ends of the divided fibres can then be seen bound up in packets, or bundles. Each bundle is composed of a considerable number of fibres ranged side by side, like the strands of a rope,and each of these fibres, when magnified by very powerful microscopes, is found to be in its turn composed of a considerable number of filaments, fibrils, or threads, which are marked across by transverse dark bands, separated from each other by lighter spaces.

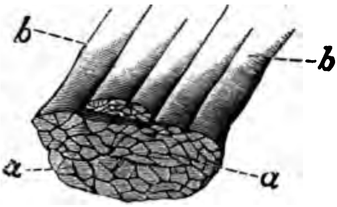

Fig. 22.—Muscular fibres cut across at *a a*, to show the bundles of smaller fasciculi, *b b*, of which they consist.

Each separate fibril is of exceedingly minute size, and seems to be made up of a series of short rods placed end to end, but separated from each other by some more transparent structure. The rods themselves are so small, in their transverse diameters, that 20,000 of them could be placed side by side within an inch. It is the rows of these rods, ranged closely side by side, with the clear space intervening between contiguous ends, which causes the appearance of dark bands crossing the bundles of fibrils, or fibres. The rods themselves, minute as they are, appear to be the parts which are concerned in the vital action of the muscle. When a muscle contracts, so as to bring portions of the rigid framework of the limbs to which it is attached nearer together, it increases in breadth as much as it shortens in length. The dark transverse bands come more closely together, and stretch out more widely from side to side.

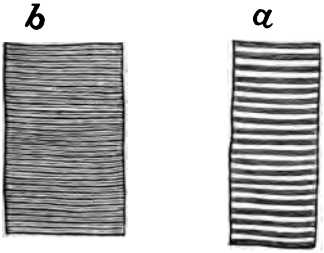

Fig. 23.—Representing a single fibril of muscular fibre with its transverse bands; (*a*) when in a relaxed and lengthened state, and (*b*) when contracted.

The bundles and elementary fibrils of the muscle are everywhere inserted into the interstices of a close network of capillary vessels, to which the blood is brought by an arterial trunk, and from which it is taken away by a venous trunk.

As the heart beats, the blood flushes through the channels of this capillary network, and as it does so, furnishes the muscular fibrils with continual supplies both of blood-plasma for the nourishment of their structure, and of blood-corpuscles freighted with oxygen for rousing their activity. Portions of the organized structures of the fibrils are consumed with the act of contraction, and converted into carbonic acid and urea, a product of which more will have to be said presently. One result of the contraction and consumption, is the generation of heat. A very large proportion of the warmth of the body is derived from this destructive contraction of its muscular fibres. About four-fifths probably of the energy developed in this way, goes into heat, and one-fifth into effective mechanical work.* So far as the muscles are concerned, it is almost certain that the muscular structure consists of two parts: one which is durable, and slow to be consumed, and which serves therefore to maintain the general form and permanence of the tissue; the other, the more active and mobile part, prone to decay,

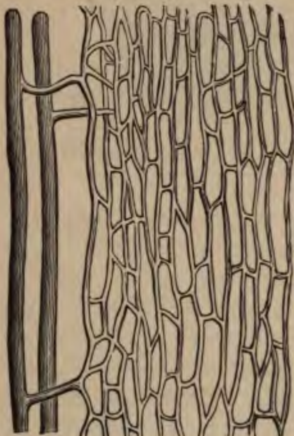

Fig. 24.—Network of capillary blood-vessels furnished to the fibres of a muscle, as it appears when those fibres are removed.

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* Some physiologists consider that one-fourth of the force developed can be employed as mechanical power under the circumstance of especial effort, but that scarcely more than the twenty-fifth part of it is ordinarily so applied.

and serving by its ready decomposition the purpose of generating and sustaining the vital movements of the fibres. The vast importance of the muscular apparatus of the animal body is strikingly expressed by the fact that a fourth part, at least, of the blood contained within the frame, is at all times engaged in maintaining the integrity and efficiency of this part of the organization.

In the nervous apparatus of living animals there are two distinct elements, which are at once recognized from each other by the circumstance that the one is composed of long delicate tubes, adapted primarily for the transmission of nervous action, and the other of thin-walled chambers or vesicles, enveloped in the meshes of very abundant capillary blood-vessels, somewhat analogous to those which are supplied to the fibres of muscles, and obviously provided for the origination of nervous action rather than for its transmission. The tubes are like the wires of the electric telegraph which carry the vibratile agency from place to place, and the vesicles are analogous to the batteries which generate the current that is so transmitted.

The ultimate tubes, or fibres, of the nervous organization, are of almost inconceivably minute dimensions. Nerve-threads have been brought within the range of visual perception, by the help of the microscope, which are so fine that fifty thousand of them might certainly be ranged side by side in the length of an inch. Of such threads it would require something like a hundred and twenty millions to make up a cord the size of an ordinary blacklead pencil. At one extremity of their length these fibrils are moulded into the form of a round or flattened rod of albuminous substance, destitute of any discoverable external covering, and somewhat resembling the thread of viscid glue which can be drawn out from a warm gelatinous solution. In that state the pulpy thread constitutes what is known as the "axis cylinder," or core, of the nerve fibre. When, however, several of these nerve cores are placed side by side for convenience of package, they are coated over, before they touch each other, by an albuminous sheath or investment, technically designated the medullary substance of Schwann, because it was first noticed by a German physiologist of that name, and afterwards by another and outer membraneous skin, termed the neurilemma.*

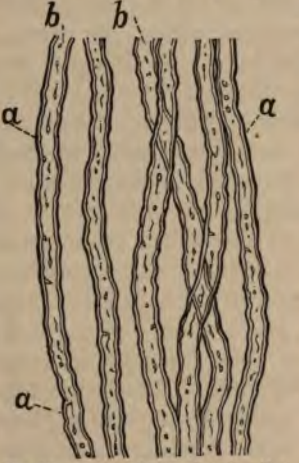

Fig. 25.—Nerve fibrils, showing the membraneous sheath, or medullary substance of Schwann (*a*) and the central axis cylinder, or core (*b*).

The nerves traced in the animal body by the anatomist are made up of a myriad of these coated fibrils, of which each one is, by this contrivance of external coats, kept from end to end perfectly distinct and isolated from its neighbours. In this arrangement, it seems to be the central core, however, that is the essential part upon which the transmitting power of the nerve depends. The external sheaths merely serve the purpose of protection.

The vesicular portion of the nerve organization is formed mainly of more or less globular vesicles of filmy membrane, containing in their interior cavities a soft, granular pulp of a reddish-brown colour. These vesicles are of a considerably larger diameter than the fibrils of the nerves, and although generally of a globular form, they frequently run out into angular corners or horns. By this means the axis-cylinders, or cores, of neighbouring nerve threads, are brought into direct communication with the granular pulp, either by the fusion of the one with the other, or by the pressing up of the one against the other, so that only a thin filmy membrane intervenes between the pulp of the vesicle and the nerve core.

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* From the Greek words *neuron*, a nerve, and *lemma*, bark or skin.

The pulp-filled vesicles of the nervous apparatus are invariably deposited within the meshes of capillary blood-vessels, which are wreathed round them in such a way that, as the blood circulates through these channels, the vesicles get saturated with it. The blood transudes through the filmy walls of the netted vessels and also of the nerve vessels with which these lie in close contact. The result of this arrangement is that the granular pulp contained within the vesicle continually gets renovated by the blood, at the same time that its vital activities are roused by the oxygen also communicated from the same source. The vital action developed in the vesicles is thus in a double sense, derived from the blood. The globular vesicles are, therefore, the originators of the subtle influence which is transmitted along the nerves. The rich, complex food brought to them by the streaming currents of the blood is changed in their interior cavities into the red granular pulp, and then the granular pulp is resolved, under the degrading touch of the oxygen, into simpler states, the result of which

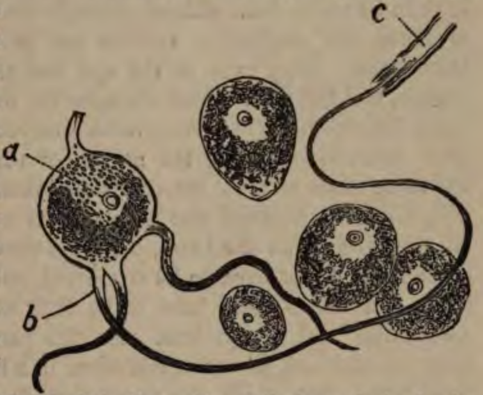

Fig. 26.—Pulp-filled vesicles of the human brain, showing a horned vesicle at *a*, with one of its filamentous projections (*b*) running into the axis cylinder of a nerve fibril at *c*.

is the setting free of force capable of being discharged along the tubular fibres as currents of nerve influence, and of being so turned to practical account. As in the case of the electric telegraph, the originators of the motor influence are stationed at each end of the transmitting threads. No nerve current is possible without their agency. Wherever impressions have to be made from without through the so-called organs of sense, the originating vesicles are provided in ample abundance. They exist in the eye, the ear, the nose, the tongue, and the skin. And wherever the impressions made upon the external senses have to be received and registered, after transmission along the nerves, or wherever response has to be made to these external impressions by some act of will, they are clustered also in countless myriads. Above all, they abound in the brain, the great central organ where sense impressions have to be converted into memories and ideas, and where ideas have to be dealt with as objects of association and comparison. In this particular instance they are enclosed, for safe protection, in a hollow casket of rigid bone, into which the nerve threads pass as the appointed means of communication with the external world.

No nerve current is possible without the originating influence of the vesicular structure. The vesicles of the external parts of the apparatus are so modified and grouped as to constitute the organs of sense. But those of the interior part are gathered in various places into clustered groups, which are known as the vesicular nerve masses, or ganglia.* Wherever these vesicular masses are gathered, there are fine nerve threads intermingled among them, as the vesicles would be of no practical avail unless there were channels for conveyance of the influences set up by their action. Thus, in the brain, which is the great central nerve ganglion of a back-boned animal, the vesicles of the different parts are connected together by fibrils that run from place to place, and that are trailed and looped about in all directions in the most intricate way. The fibrillous part of these collected nerve masses is, however, at all times distinguished from the vesicular parts, with which it is so intimately associated, by the whiteness of its structure. The nerve fibrils are invariably white. But the vesicular agglomerations are as commonly of a grey hue, on account of the presence of the red granular pulp in the interior of the vesicles, and also of the great abundance of red blood which is distributed among them by the network of capillary vessels. Blood is, indeed, so plentifully supplied to the brain, that this great central organ of nervous life appears to receive something like ten times as much as any other vital structure of the same dimensions. In the human brain, the grey vesicular mass is principally arranged as crumpled-up and convoluted folds; and the white fibrils are gathered together beneath and within for convenience of transmission from the brain to other parts of the body with which it is brought into communication; or for passage as commissural* or connecting cords between different parts of the brain, which have to arrange and compare the impressions of sense, and to organize them into ideas. These several parts of the brain structure are, however, of such surpassingly minute dimensions, that a fragment of the pulp, not larger than the head of a small pin, must certainly contain many thousand commingled vesicles and fibres. A distinguished physiologist has been at the trouble to calculate that there cannot be less than two hundred millions of nerve vesicles in the convolutions of a single human brain.

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* From *ganglion*, an old learned name for a little swelling or tumour, seated upon a tendon immediately beneath the skin.

In all probability it is much the same with the brain as it is with the muscles. Some part of the tubular fibres and globular vesicles is composed of albuminous membrane, which being of a comparatively fixed and unchangeable nature, serves to preserve the integrity and general form of the organ, whilst other parts are constituted of more versatile substance, prone to be thrown into explosive decomposition at every fresh touch of the degrading oxygen. But, however this may be, it is certain that brain-substance is consumed by the operations of sensation and thought as much as muscle-fibres are by the mechanical work of movement. Each red corpuscle that enters the vascular network of the brain, with its charge of oxygen taken up in the lungs, makes that oxygen over to the granular pulp of the vesicular substance for the stimulation and support of its vital operations; and with each discharge of nerve-force that is passed from this pulp to some tubular thread atoms, of carbon, hydrogen and phosphorus are set free in some loose and degraded form of association, and returned to the plasma of the blood. The nerve-influence developed in the vesicular mass is as essentially connected with the oxidation and burning of some constituent of the granular pulp, as flame is connected with the burning of the combustible constituent of a candle or lamp. The nerve-influence set free by this operation has been likened to a current of electrical force. But it is clearly of a very different nature to that, because it moves at a much more sluggish pace, and follows an altogether different rule of progression. It has been ascertained that it traverses the axis cylinder of a nerve at the rate of about two hundred feet in a second, whereas the transmission of electrical force is made with a speed varying from thirty to one hundred and ninety millions of miles in a second. In the transmission of the nerve-force there is most probably an actual change in the condition of the nerve-pulp, and actual decomposition of its complex particles, passed on from molecule to molecule, and this would naturally consume more time than the transmission of a mere vibratory tremor amongst elastically-strung particles.

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* The white fibrillous cords which connect different parts of the brain are called "commissures," from two Latin words, *con* and *missus*, which signify "together" and "sent." They are bundles of nerve cords sent together from place to place.

The molecule of the nerve-pulp is obviously a very complex agglomeration of constituent elementary atoms. It is generally considered by physiologists that something more than five hundred atoms of the elementary constituents are required to construct each molecule. This conclusion has been formed because phosphorus is indispensable amongst its ingredients, and because to each single atom of phosphorus there seems to be attached five hundred and eight atoms of the other elements. As the atom of phosphorus is conceived to be an altogether indivisible substance, and as there is associated with the phosphorus as large a proportional amount of the other elements as has been named, it follows that there must be at least this number of constituent atoms concerned in the fabrication of each molecule. To infer that a molecule was formed of less, would be to assume that a portion of an atom of phosphorus in itself indivisible, could be apportioned to it. The complex product, which seems to be the source of vital activity in the human brain, was discovered by Dr. Oscar Liebrich in 1865, and by him called protagon.* But, like other complex productions of vital organization which have been alluded to, this body seems to be the highest and last of a progressive series of complex substances leading gradually up to its full maturation, and the first of a descending series produced afterwards from its step by step degradation under the reducing touch of oxygen. That protagon itself is of a highly combustible character, and very prone to be so degraded by the influence of oxygen, is substantially indicated by the fact that four hundred and sixty-nine of the five hundred and nine atoms attributed to the molecule are carbon, hydrogen, and phosphorus, all individually inclined to contract combustive combinations with oxygen with great development of heat. The nerve-vesicle is thus mainly composed of a kind of oleaginous pulp mingled with minute quantities of the highly inflammable element phosphorus.

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* From the Greek words *protos*, first, and *ago*, to lead; implying, as it were, that the substance is a leading actor in the work of organization.

Symbol representing the chemical composition of a molecule of protagon, $H^{308}N^{5}C^{160}O^{35}P^{1}$.

The brain-substance is perhaps the most delicate and refined of all the structures that have been provided in the animated frame, consisting as it does of a soft vesicular pulp, penetrated everywhere with streams of flowing blood, and obnoxious in the highest degree, to the chemical influence of meddlesome oxygen. As the blood is flushed through the pulp of the brain, some part of the frail material is with each effort of perception and thought, resolved into simpler forms of molecular association, and, in that condition, carried away in the onward currents of the blood. But new pulp is at the same time furnished from the organizable plasma of the blood. If at any time the circulation of the blood through the brain is stopped, insensibility and absolute incapacity for the performance of any intellectual or volitional operation immediately ensues. Sleep is an approximate approach to this torpor of the brain caused by the reduction of the current of the blood to a very slow rate of movement. This is brought about by contracting the dimensions of the capillary channels that furnish the supply. During sleep the brain-pulp is bloodless and pale. The vital stream is sufficiently maintained to supply nourishment for the repair and renovation of the exhausted pulp, and it is not sustained in sufficient force to keep up the degradation and waste of that substance. During the energetic action of the brain, on the other hand, a strong current of blood is turned on, and the pulp is stimulated and consumed with corresponding rapidity; and even more than this, the blood is most strongly directed to that part of the brain which is most especially concerned in the work that is on hand. The vessels, which distribute the blood to any given tract of the brain are either diminished or enlarged according as that part is to be left at rest, or to be brought into an energetically active state. There are, indeed, fine nerve-threads and a service of beautifully organized muscles attached to the blood-vessels of the brain, which are employed for the purpose of closing, or opening the channels of supply, now here, now there, as the case may be. The nerves, that convey the influence which dilates the vessels and augments the activity of the brain are derived from the spinal cord. But those which govern the contraction of the channels and the diminution of the activity of the pulp, are derived from ganglionic vesicles, known as the sympathetic system, which are the nerve-centres of organic life, distributed elsewhere about the body, and not forming a part of the spinal cord and brain. The familiar action of blushing is an instance of the increased supply of blood to a particular part, when its blood-vessels are dilated and enlarged. The flush of redness which then appears upon the cheek, is due to a sudden rush of blood to the minute blood-vessels of the skin. A blush of a similar kind flushes the grey pulp of the brain whenever it is roused into energetic activity. Some physiologists believe that attention to any particular subject of thought is accomplished mainly by the increased flushing of that part of the brain which is concerned with that particular mental operation. The greater facility with which mental work of a specific kind is performed after the attention has been repeatedly given to it, is unquestionably due to the gradual enlargement of the vessels under the influence of augmented and frequent use, and to the more ready means which are thus provided for deluging particular tracts of the brain with blood.

LECTURE VIII.

The Action of the Kidneys and Skin.

THE kidneys, although of considerably smaller size than the liver, are by no means of less importance to the vital actions of the living economy. They are of great consequence not only as excreting and purifying organs, but also in another sense. They provide the chief outlet for the water when it has accomplished its carrying task. They are of exceeding delicacy of structure, and are perhaps unsurpassed by any other part of the organized frame in their extraordinary adaptation to the exquisitely balanced work which they have to perform.

Like all the other organs which concern themselves with the removal of worn-out material from the blood, the kidneys essentially consist of an enormous number of living vesicles, clustering within a delicate network of blood-vessels, and, at the same time, intimately associated with a system of tubes or pipes, laid down to receive and carry away the waste material which is drawn out of the meshed capillary vessels in a liquid state. In this particular, therefore, they very nearly resemble the construction of the liver. But in the kidneys, the arrangement is specially modified to meet the circumstance that the regulation of the outflow of waste water has as much to be provided for as the removal of solid refuse in a state of liquid suspension.

There are two kidneys, and they are placed in the *region* of the loins, one on each side of the backbone, and each one of these is supplied with blood by a branch, sent off from the main trunk of the artery which descends from the heart to the lower part of the trunk, and is known as the renal artery.

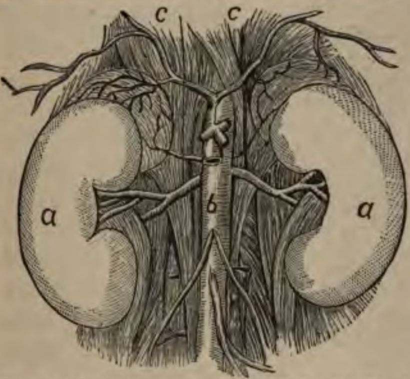

Fig. 27.—The kidneys (*a a*), supplied with blood from the main arterial trunk (*b*) (descending aorta) by the renal arteries (*c c*).

Each renal artery, having passed into the interior of a kidney, through the strong outer coat of that organ, divides itself into subordinate branches, and finally distributes itself into a thickly-set network of capillary vessels, through which blood can be flushed, and be afterwards gathered up again into veins, that at last issue in one main branch. This runs to, and terminates in, the venous channel, corresponding with the descending arterial trunk, which carries back the collected blood to the right receiving chamber of the heart.

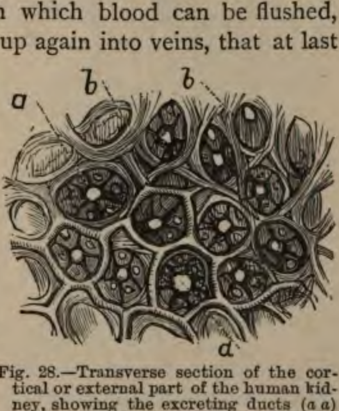

Fig. 28.—Transverse section of the cortical or external part of the human kidney, showing the excreting ducts (*a a*) cut across, with the pavement of lining vesicles (*b b*) surrounding the inner cavity of the duct.

The secreting vesicles of the kidney, which extract the waste material from the blood, are, however, disposed in a very compact and definite way. They are pavemented round the inside of the excreting tubes, as a kind of lining, having the hollow cavity, or canal, within.

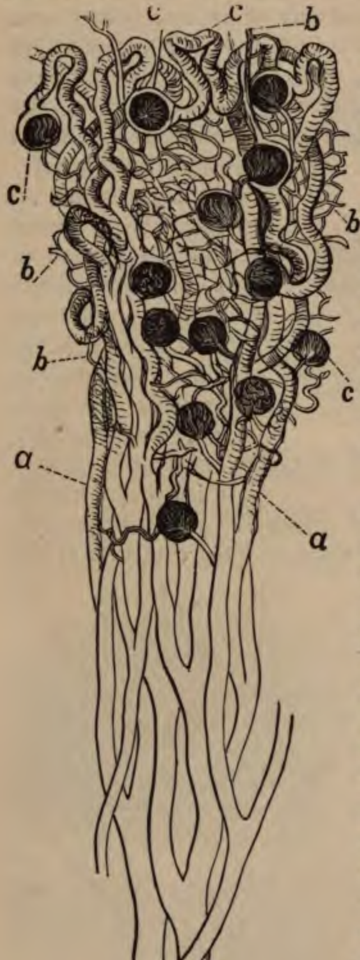

Fig. 29.—The excreting ducts, or tubuli uriniferi of the kidneys (*a a a*), intermingled *with the capillary* blood-vessels (*b b b*), *and the Malpighian* capsules (*c c c*) in *which some of these* ducts terminate.

The network of blood-vessels is distributed over the outside membrane of the tubes, and so comes very near to the lining vesicles, to which it has to supply the material for secretion. The excreting ducts begin in the outer part of the substance of the kidney as a series of loops, which are drawn gradually together to constitute larger and larger tubes of outflow.

The whole of these tubes, it will be understood, are lined by the pavement of secreting vesicles just described. A portion of them, and a portion only, have dilated, bulb-like, or capsular enlargements at their ends (see Fig. 29), which are termed the Malpighian capsules, because they were first observed and described, about the year 1682, by the Italian anatomist, Malpighi. These capsules will have to be more particularly alluded to presently, on account of the important use to which they are put. The excreting portion of the substance of the kidney thus mainly consists of looped and winding tubes, so small that from three hundred to six hundred of them can be packed side by side within an inch, and the round capsular bodies previously mentioned. The capsules themselves are so minute and numerous, that there cannot be less than two millions of them in each human kidney. As will presently appear, the great abundance of these capsular dilatations of the excreting ducts is of the utmost consequence to the efficient action of the organ in one important respect.

The entire series of excreting tubes are, in the end collected together into one funnel-like cavity or basin, termed the pelvis of the kidney. This passes the liquid secretion on into a tube, called the ureter, which ultimately empties it into the large reservoir known as the bladder.

The quantity of liquid excretion removed by the kidney varies in adult human beings, at different times, to a very large amount. Thus, it is in much larger quantity in the cold weather of winter than in the warm season of summer, when a larger amount of water finds its way out from the blood by transpiration through the pores of the skin. The average quantity, however, is between two and three pints every twenty-four hours. Of this, a twenty-second part is solid material, held in solution, and the rest water. The

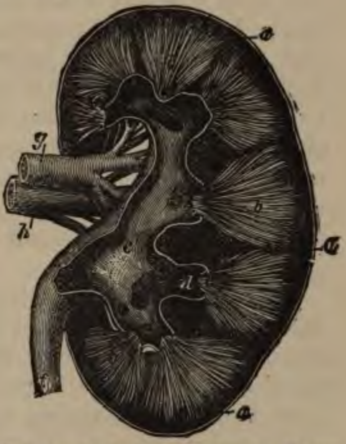

Fig. 30.—Section of the human kidney, showing the tubuli uriniferi of the cortical parts (*a a*), opening by papillæ (*b b*) into the funnels of the pelvis (*d*, *e*), which terminate in the ureter (*f*); the renal artery and vein (*g*, *h*).

solid part, which commonly amounts in the adult to something like nine hundred grains in the twenty-four hours, is all waste material, which has performed its appointed work in the body and then been washed away as refuse substance. One-half of the solid material thus dissolved in the liquid secretion of the kidney is a peculiar substance distinguished by the chemist as urea. This urea is essentially the waste material of the flesh and brain of the animal body—the most highly nitrogenized portions of the structure. Work, both of muscle and brain, increases the quantity of it that has to be removed, which sinks sometimes as low as two hundred grains in the twenty-four hours, but may rise as high as seven hundred grains. The average quantity of five hundred grains is, it will be observed, a little more than one ounce. Urea is, in fact, the nitrogenized constituents of the frame, such as albumen, fibrin, and the other more complex products of organization, on their way to final resolution into their ultimate elements. The last stage of this resolution is conversion into carbonic acid and ammonia.

All the highly nitrogenized constituents of the frame are in the end turned back into the carbonic acid and ammonia, from which they were primarily constructed by the plant. But it would be inconvenient that this resolution into the last stage but one of destructive degradation should be made within the body, because ammonia is a pungent and irritating compound, whose presence would hardly be borne by the living ducts through which it would have to be washed. The carbonic acid and ammonia are therefore retained in the form of urea, which is bland and unirritating, until they are outside of the body. The urea is then rapidly converted into carbonic acid and ammonia by further additions of oxygen derived from the air. Each molecule of urea, whilst incorporated with the water of the liquid excretion, seems to consist of one atom of carbon, two atoms of nitrogen, four of hydrogen, and one atom of oxygen.

Symbol expressing the chemical composition of a single molecule of urea, $H^4O^1N^2C^1$.

The addition of two atoms of hydrogen, and one atom of oxygen to one of these molecules of urea, suffices at once to convert it into a molecule of carbonic acid, and two molecules of ammonia; as may be expressed directly to the eye by means of the following diagram, where the initial letters represent atoms of the elementary constituents.

Urea.				Extra.		
	C	O	……	O	=	Carbonic acid.
N	H	H	…..	H	=	Ammonia.
N	H	H	……	H	=	Ammonia.

The additional atoms of oxygen and hydrogen, required for this final act of destructive change, are readily furnished from some other portion of the degrading substance, or from air and water. It will be observed how very simple the composition of urea is, containing, as it does, only eight constituent atoms in each of its molecules, when compared with the more complex substances such as albumen, fibrin, fibrinogen, hæmoglobin, and protagon.

But the crowning marvel of the structural arrangements within the kidneys, still remains to be described. The organ is not merely a piece of secreting apparatus for the separation of waste, and to a certain extent, therefore, noxious material from the blood; it is also a floodgate for the escape of the water itself from the channels of the blood, after it has performed its carrying task. Since water has to be introduced afresh with each new contribution of the digested and liquefied food, as much water at least must be removed from the interior cavities of the body, in order that there may be room for it. As water, with its vivifying and nourishing burden, has to be continuously poured into the living frame, water must also be, in a similar amount, poured out from its inner chambers and channels. In other words, it must be washed through the vessels of the circulation, entering by one gate, as it were and passing out by a different series of portals. And more than this, the kidneys are not only the chief floodgates for the outflow of water, they are also self-regulating floodgates, which open a wider passage whenever a more free and unimpeded escape is required, and which narrow the passage whenever the outflow needs to be less. In order that the best physical state, for the ready flowing of the blood through the narrow channels of its vessels, and for due infiltration through the permeable membranes of the various structures, may be preserved, a due liquidity of its own substance must be maintained. It must be neither too thick, nor too thin, in consistence. In other words, it must retain, among the other ingredients of the plasma, the exact proportional quantity of water, which is the best for its mobile and penetrating work. But under the varying circumstances in which living animals are placed, this condition can only be secured by the agency of a self-regulating apparatus, at all times ready to let off the water when it is accumulating to excess, and to husband the supply when that is less copious. Such a self-regulating apparatus of the most exquisitely perfect kind is presented in one part of the organization of the kidneys.

It has been already stated that many of the convoluted excreting ducts of the kidneys end in blind bulbous dilatations, or capsules (the capsules of Malpighi), instead of passing freely on like the rest, into the collecting funnels and channels of outflow. These bulbous capsules, thus inserted amidst the excreting ducts, are the self-regulating valves which control the escape of the water. They have nothing whatever to do with the abstraction of urea from the blood. They concern themselves only with the thin liquid, water, and such soluble matters as can be held intimately united with it, without risk of being filtered off when it exudes through fine lining membranes, as is the case with bodies like sugar and salt.

The construction of the capsules of Malpighi, these floodgates of the kidneys, is of a very remarkable kind, in order that they may be adapted for their office of regulating control. Each capsule contains in its dilated, or bulbous interior, a little knot of rolled up blood-vessels, which is supplied from the general network of capillaries already described.

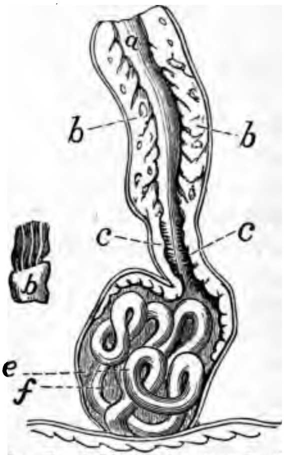

Fig. 31.—A Malpighian capsule of the human kidney greatly magnified. *a*, being an uriniferous or excreting duct, lined at *b*, by pavement-vesicles serving for the secretion of urea, and at *e* by ciliated vesicles (of which one is shown apart at *d*) ; *e*, is a contorted capillary blood-vessel rolled up in the interior of the capsule, and exhaling water from the blood into the capsule *f f*, which is then discharged through the uriniferous duct, *a*.

The blood, which has traversed the contorted channel of the little rolled up knot of capillaries, passes on by a single outlet to mingle with the general flow in the widely-diffused network, that is the source of blood-supply to the urea-secreting vessels. But the effective consequence of this interposition of the convoluted tuft of vessels on the way to the general network concerned in furnishing the secretion, is that a certain amount of additional resistance, or impediment, is offered to the passage of the stream in the rolled-up knot, and greater pressure is therefore exerted upon the walls of its vessels to overcome the obstruction. As soon as this pressure begins to tell, the thinnest portion of the blood, that is, the water, commences to ooze through the filmy wall of the capillary vessel, and to find its way into the cavity of the capsule which surrounds the little tufts, and communicates with the passage of outflow. Just within the narrowed neck of the capsule, the commencement of the duct is set round with a compact array of little living vesicles, fringed with lashes, which keep these lashes in waving motion, and so drive the water on from the capsule to the channel of discharge, where it is finally mingled with the urea that is in process of being drawn from the blood through the walls of the duct by means of its layer of absorbing vesicles. The quantity of water, which is thus added to the general outflow, depends upon the mere physical influence of the liquid pressure exerted within the contorted vessels of the capsule. It has nothing to do with the living force that is concerned in the operations of the secreting vesicles. Whenever there is increased pressure upon the convoluted vessel, from an undue augmentation in the quantity of the circulating blood, more water exudes through its walls, and gets into the surrounding free cavity of the capsule, to be thence passed on to the channel of outflow. But, whenever the pressure upon the convoluted vessel is reduced, in consequence of a diminution in the volume of the circulating blood, the entire liquid passes on to the network of capillaries, which furnish urea to the further portions of the excreting duct, instead of exuding its watery parts through the cavity of the capsule. Both urea and water are separated from the blood in the kidneys. But the one can be increased or diminished as an excretion without interfering with the other. More water is poured out through the Malpighian capsules, when the blood is highly charged with the thin most readily exudable liquid, and less is poured out, when the water in the blood is not superabundant, or in an actual state of deficiency. It is in this way that the discharge of water from the blood is automatically, or spontaneously, regulated, the floodgates are opened or closed, merely by the increase or diminution of the fluid pressure to which they are subjected.

Various other solid substances, besides the waste urea, are washed out of the blood through the kidneys. But these are all bodies capable of being freely dissolved in water, and of being carried with the water through the fine, filmy membranes without being filtered off. They are most of them of the nature of inorganic salts; such compounds as chloride of sodium and the sulphates of potash, soda, magnesia, lime, and the rest. They are all waste matters in process of removal from the living structures in which they have played their part. Something like four hundred grains of substances of this kind are ordinarily cleared away out of the blood by the kidneys every day, and of this, very generally quite one half is common salt, the material that is so largely and constantly taken with the food. But these very soluble ingredients all pass through the contorted vessels, or tufts of the Malpighian capsules, and not through the vesicles that secrete the urea.

The strain which is apt to be put upon these most delicate organs, by any accidental derangement or irregularity, will easily be conceived when it is understood that the work they have ordinarily to perform is to get rid of five hundred grains of urea and four hundred grains of saline matters every day, as well as of the waste water. It has been estimated that in the usual process of flushing with blood, not less than two thousand pounds of liquid pass every twenty-four hours through the vessels of each pair of human kidneys of average size and activity.* Of course this large quantity can only be made up by passing the same material through the kidneys, by a process of recurrent circulation, over and over again. Each grain of urea requires for its production the destruction of three grains of more highly organized substance. The force which is involved in the production by this destructive decomposition of five hundred grains of urea, would suffice, if converted into mechanical power, to lift seven hundred and four tons one foot high.

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* This is the estimate which has been formed by the French physiologist, M. Brown Sequard.

The red deposit, which frequently appears as a secretion from the kidneys, and which is known as uric, or lithic acid, is really imperfectly developed urea, which is very much less soluble in water in that crude state, than it is when perfectly formed. It is waste of the nitrogen-containing textures of the frame, which has not been sufficiently oxidized to convert it into the bland and soluble substance that is best suited for its removal through living vessels. There is, at all times, a small amount of this imperfectly oxidized urea, or lithic acid, in the secretion of the kidneys; at the least as much as four grains and a half in the quantity produced in twenty-four hours. But, in certain states of disorder, as, for instance, in gout and kindred diseases, the amount is occasionally increased sevenfold, or to as much as thirty-two grains in twenty-four hours.

As would naturally be expected, the external surface of the body is itself an organ of excretion. The opportunity is taken, in carrying out the operations of life, of discharging at once no inconsiderable portion of the worn-out substance of the frame through its outer covering. The body of an animal is, in all cases, clothed in a stout and tough layer of membrane, which is called the skin, and which serves the very useful purpose of keeping the various organs conveniently packed together, and of at the same time protecting them from the irritating influence of the air, and from mechanical injury. This external covering is formed of fibres of strong connective tissue woven together with several outer layers of dried and flattened scales. But there is also an abundance of fine blood-vessels mingled in with the fibrous and less vital part. This is significantly shown by the fact that the sharpest needle cannot be pushed anywhere into the skin without wounding some of the small vessels, and causing a drop of blood to escape through the opening. The entire skin is filled with a capillary network of blood-vessels corresponding very much to those which have been described as existing in the substance of the liver, the kidneys, the muscles, and the brain.

The dry, external scales, which constitute what is termed the cuticle, serve the general purpose of preventing the evaporation of water from the liquid substances contained within. But the skin is, nevertheless, not absolutely impervious to moisture. It is pierced with a vast number of minute holes, or pores. These pores of the skin are indeed so numerous, that it has been estimated there can scarcely be less than seven millions of them on the body of a full-grown man. With strong magnifying glasses three thousand can be counted to the square inch on some parts of the skin.

But these pores are not merely holes, or pits drilled through the compact substance of the dry, scaly cuticle, and subjacent fibrous membrane. They are really the open mouths of little tubes which come out from within. Each tube proceeds inwards from the pore as a slightly waving duct that passes first quite through the thickness of the skin, and then is folded up and rolled round upon itself into a kind of ball.

Each of these tubes, if drawn out so as to unroll its convolutions, would be found to be something like a quarter of an inch long, and the seven millions of them existing in the skin of a full-grown man, if placed end to end, would thus make up a length of not less than twenty-eight miles. The rolled-up and knotted portions of these tubes of the skin are intimately intermingled and associated with the meshes of the capillary blood-vessels, so that moisture and vapours from the warm streaming blood can easily exude and steam through into the channels of the tubes. They are also supplied, where they are thus intermingled, with secreting vesicles which help to draw some part of the ingredients out of the blood, and pour them into the tubes. The tubes in reality are excreting ducts, and the excretion which they serve to remove is familiarly spoken of as perspiration,* because it consists of moisture and vapour exhaled or "breathed" through the skin.

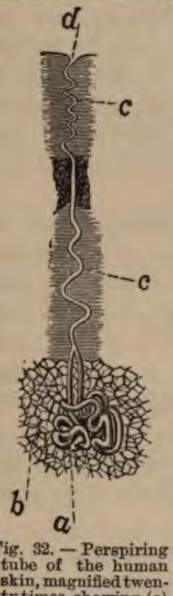

Fig. 32. — Perspiring tube of the human skin, magnified twenty times, showing (*a*) the convolutions of the origin of the tube rolled up in the cellular texture and fat (*b*) lying beneath the skin, and leading through its substance by the spiral duct (*c*) to (*d*) the pore which perforates the external surface for the escape of the perspiration.

The rolled-up tubes are first filled with vapour, which is thrown into them from the blood, and this is then poured out into the air through the open pores that form the external mouths of the tubes. By the ingenious contrivance of hollowing out the substance of the skin into these winding cavities, a larger surface for the exhalation of vapour is supplied than would have been at command if the whole external surface of the skin had been capable of exudation. But a control of the process is at the same time secured, because the external pores can be more opened or more closed, according to the exigency of the moment. In ordinary circumstances and in a general way, the exhaled vapour escapes through the pores as a quite invisible steam, which, in that state, is known as insensible perspiration. When, however, from the rapid coursing of the blood through the capillaries and from other conspiring influences, the quantity of the exhalation is very materially increased, it is condensed into drops of visible moisture as soon as it issues from the pores, and in that state trickles down upon the outside of the skin as manifest and sensible perspiration.

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* From the two Latin words *per*, through, and *spiro*, to exhale.

The quantity of vapour which passes out as exhalation through the pores of the skin, varies with altering circumstances, within very wide limits; and necessarily so, because it is an adjustable process designed for regulating the heat of the body. Whenever this heat tends to augment too rapidly, the pores of the skin are freely opened, and the interior spaces of the body are cooled by more abundant evaporation. As a general fact, as much water again escapes from the body through the pores of the skin as passes out from the lungs with the breath. Some careful observations, made by a German physiologist, gave two pounds as a fairly probable estimate for the average quantity of liquid that is poured out through the skin every twenty-four hours; but this quantity is capable of being increased sixteen, and even twentyfold for short periods, under special circumstances. The quantity of the perspiration is ordinarily increased by the warmth and dryness of the air, and diminished by its coldness and moisture.

The perspiration although chiefly, is not entirely, composed of water. It has mingled with it a certain quantity of waste material analogous to the urea secreted from the kidneys, and which is essentially an excretion drawn from the blood. It is, indeed, just as urea is, waste of muscle and brain and of other worn out structures of the frame. Very rarely less than one hundred grains of this solid refuse are passed out through the skin in an interval of twenty-four hours, and frequently the quantity amounts to considerably more than this. The skin and the kidneys in reality act as co-operative, and also as sympathetic and compensatory, organs. In hot weather and during active exertion, the skin takes the lion's share of the work; but with cold weather and less active exertion, the pores of the skin are constricted and closed, and the work is chiefly performed by the kidneys. One obvious reason for this arrangement is that, in periods of exceptional heat, the removal of the water from the outer surface of the body in the form of exhaling vapour instead of from the internal surfaces as liquid, may be made subservient to the reduction of a too high temperature. Perspiration is, in this sense, the antagonist and opposite of respiration. Respiration blows up the hidden fires of the system to raise its temperature above that of the surrounding air; perspiration carries away considerable portions of the heat which is thus generated. The transpiration of aqueous vapour from the lungs, however, assists the exhalation from the skin, and is thus so far a kind of supplement to its action. If a piece of wet linen be laid upon the skin, and left there exposed to the air, the evaporation of its moisture very soon produces a sense of coldness, or chill. The heat of the skin is used up in converting the moisture with which the fibres of the linen have been saturated, into vapour, or steam. The vapour flies away with the warmth, and leaves the skin impressed with the sensation of cold. Exactly in the same way, the escape of the vapour of the blood through the pores of the skin, serves to lower the heat.

The most agreeable external temperature in which the body can be placed under ordinary circumstances and when lightly clothed, is from 62 degrees to 65 degrees of Fahrenheit's scale. The internal temperature of the body is kept, by the balanced action of its internal combustion and external transpiration and cooling, at from 98 degrees to 100 degrees of the same scale. This is termed blood-heat, because it is the natural temperature at which the blood of the higher kinds of animals is maintained. The oxidation by breathing and through the combustive destruction of the vital textures, and the evaporation through the skin are so adjusted to each other, that with the help of clothing—which retards the loss of heat from the external surface through radiation—this natural temperature of nearly 100 degrees is sustained, whatever may be the external conditions. It is only in cases of febrile disease, in which the textures of the body are too rapidly consumed, that the natural heat rises above 100 degrees. It is then occasionally raised to as much as 108 degrees. This is in all cases the result of chemical action and destructive decomposition being quickened beyond the ordinary standard of health. The increased heat is invariably connected with waste of the body and loss of weight. It has been ascertained that an increase capable of raising the temperature 5 degrees can only be produced by the generation of an additional eighth part of the heat ordinarily furnished by the combustion of the tissues. It is no uncommon thing in wasting fevers for double the usual quantity of urea to be discharged from the system, all of which is, of course, derived from the quickened disintegration of the nitrogen-containing structures of the body. In such circumstances, every four grains of this augmented secretion of urea is produced by the expenditure of force which, if mechanically applied, would have sufficed to lift a weight of five tons one foot high. This wasteful expenditure of vital force in fevers, is obviously the immediate caûse of the debility and emaciation that attend upon the progress of such disorders.

LECTURE IX.

Nutrition, Work, and Heat.

SOME careful experiments made by the German professor, Ranke, seem to indicate that the amount of the different kinds of food-substances, which are required to be supplied to a human body of average size every twenty-four hours, in order to maintain its bulk and weight, and to support its healthy activity and vital operations, is something like 1550 grains, or 3¼ ounces, of nitrogen-containing flesh, or analogous vegetable gluten, known technically as proteids; the same quantity of fat; 3720 grains, or 7¾ ounces, of hydro-carbonaceous food destitute of nitrogen, distinguished by physiologists as carbo-hydrates; and 388 grains, or ¾ of an ounce, of salts of various kinds; and that about 40,000 grains, or a little more than five pints, of water, are needed for the work of transport and preparation, and for the washing away of the refuse waste produced by the destructive decomposition of the tissues. Professor Ranke found that upon such a daily allowance of food, he neither gained nor lost in weight, and that he was kept in excellent health. Any amount of either of these several classes of food-substance that is introduced into the body in excess of these quantities, may therefore, in the light of this experience, be looked upon as superfluous material, which has to be cleared away out of the system without yielding nourishment, or vital strength; as so much dead weight, which has to be got rid of, and not only so, but which must be got rid of at the cost of an additional strain put upon the excreting organs. In ordinary circumstances, some dead weight of this kind is unavoidably introduced, and dealt with. More food is usually consumed than is required for the mere support of the vital structures and operations. That, however, is taken into account in the arrangements of the system, and is productive of no important derangement in it, so long as the excess is kept within reasonable limits. In all vigorous and healthy frames, there is a reserve of reducing and excreting energy, which can deal safely with the superfluity. It is only when the excess is in unreasonable quantity, or when the excreting organs are in a defective state, that derangement of a grave kind is liable to occur. But it is then apt to be produced, and occasionally at the cost of very serious penalties.

When some such standard diet as the one just spoken of, consisting of a due intermingling of proteids, fats, sugars, starch, and mineral substances, is taken into the body of a healthy human being, one part of the introduced food, after it has been duly prepared, and mingled with the blood, is used in repairing the actual waste of the tissues. Old, worn out, and therefore useless material is removed, and fresh material is deposited in its place. That portion, therefore, is applied to what may be termed constructive service. Another portion of the introduced food is consumed in giving movement and activity, in furnishing energy and force, to the textures that are so built up and sustained. This, it will be remembered, has been already incidentally explained upon another occasion, when the structure and uses of muscle, nerve and brain were spoken of. It was then pointed out that, in those very highly vitalized and most energetic structures, one part serves the purpose of constituting a compact and slowly changing frame which gives its visible characteristics to the tissue, whilst the other part is the seat and source of the energy, which is used up and destroyed with each movement that is produced, or operation that is carried on. There are thus two different purposes which food-substance serves—the nourishment of structure, and the evolution of action.

But the movements and operations, which are sustained by food, are themselves also of two different kinds. There are certain movements which are of necessity kept up within the body itself without any cessation, or intermission. Such are sustained in the beating of the heart, and in the expansion and contraction of the chest in breathing. All movements of this unintermitting and involuntary character may be distinctively spoken of as internal work. It is effort which is applied to the maintenance of the integrity of the mechanism. Yet other movements, which are of a voluntary and frequently intermitted character, such as the action of the limbs in walking about, or in performing any kind of mechanical task, are more properly external work. They are the functions for which the animated creature has been primarily designed. Some of the operations of internal work are of a partially intermitting character, such as the production of a portion of the secretions, the employment of the organs of sense, and the exercise of the mental faculties. But the same necessary condition applies to them, as to the rest: they are all supported by the consumption of food, of which some part is appropriated to the maintenance of the healthy integrity of the organ, and some part is devoted to the accomplishment of work.

The food, which is destined to this double purpose, is carried in the form of streaming blood to the capillary network of blood-vessels, which, as has been explained, is distributed everywhere throughout the textures of the body. But, as the membrane of which these universally distributed capillary vessels is composed, is of the most exquisite delicacy and fineness, the more fluid portion of the blood exudes through it as a kind of lymph, when the force of the heart's stroke falls upon the streaming liquid. The lymph having in this way escaped through the filmy walls of the vessels, saturates and bathes the external spaces that lie between their meshes. The vesicles grouped in those spaces, whether they have the form of secreting cells, of contractile fibres, or of pulp-filled brain-substance, drink in the lymph, and take from it the ingredients which they need for their own subtle operations. The difference of these operations, whether they be those of secretion, of muscular contraction, or of nerve-action and the rest, is entirely due to the difference of the vesicles that are operating in each instance. The individual vesicle in each case selects from the lymph just the ingredients which it requires for its specific work, and acts upon them in accordance with its particular proclivity and habit. In some instances the passage of the ingredients, which are selected by the vesicles, occurs directly from the blood to the cavity of the vesicle. The filmy walls of the vesicles and of the capillary blood-vessels lie in close contact, and the liquid lymph exudes from the capillary vessel to the vesicle, and from the vesicle to the vessel, under the influence which disposes unlike solutions to mingle together when they are only separated from each other by a partition of permeable membrane. But, in both cases, the ultimate result is precisely the same. The vitally-acting vesicles select from the blood what they want for their specific purposes, and operate upon it according to their own constructive capacities and dispositions.

The conditions thus dwelt upon exist in the organs of special sense precisely as they do in the other organs that have been alluded to. Every one of these, which serve to connect the inner perceptive powers of the creature with the external world, are abundantly supplied with vesicles endowed with the power of selecting ingredients from the blood, and of changing their molecular constitution in order that activity and energy may be evolved out of the change. No perceptible impression can be made upon an organ of sense excepting as a concomitant and result of the transformation of material substance. An artist cannot look at a landscape without using up food in the act. In the case of the eye, there are retinal vesicles and intermeshed capillary blood-vessels spread out together at the back of the eye-ball for the reception, transmutation, and transmission of the vibrations of light. In the ear, a similar arrangement of vesicles and capillary blood-vessels is made within the bone-invested cavity of the organ, to catch and register the air vibrations which are the effective source of sound. In the nose, vesicles and blood-vessels receive the impact of the volatile emissions that issue from odoriferous bodies. In the mouth, vesicles and blood-vessels, bathed with a viscid and tenacious liquid, catch and act upon the sapid substances which are the objects of taste. In the skin, vesicles and blood-vessels are grouped into little papillary projections, which are acted upon by contact and pressure, and by changes of temperature. In every one of these organs, sensory activity, in whatever form, is essentially connected with the consumption of food, a portion of which is applied to the renewal and support of the structure of the organ, and a portion to the performance of its energy-producing functions.

The interpretation of the manifold processes which are involved in the conversion of food into animal activity, is a matter of quite recent date. The first steps which were taken towards its accomplishment were, perhaps, those which were set as lately as the middle of the present century, by Professor Liebig, of Giessen, when he entered upon his remarkable investigations as to the nature of food. But, although he thus ranks as the great pioneer in this branch of physiological inquiry and discovery, some of the views which he entertained have had to be materially modified by subsequent research. Thus, he believed that the nitrogenized ingredients of the food were exclusively used for the building up and maintaining the structures and structural activity of the body, whilst the fats, starches, and sugars were as exclusively appropriated to the support of respiration and the production of heat. It is perfectly true, as Liebig affirmed, that the body of the animal consists of the same general classes of ingredients as the food; that it is made out of nitrogenized substances, now generally distinguished as proteids, because they constitute the material frame-work of the structures—of fats, and of the so-called carbo-hydrates of which starch and sugar are the types. But it is not true, as he implied, that the proteids, built up and stored by the plant, become the proteids of the animated frame, or that the oils and starches and sugars of the food become the fat, glycogen, dextrin, and sugar of the animal body. The fact seems rather to be that these several principles of the food are more or less transformed and mingled together after they have been subjected to the digestive operations of the stomach and converted into blood; and that they are then rearranged under some comprehensive system of selection and reorganization before they reappear as constituents of the animal textures. The proteid, or nitrogenized food is split up and resolved into its elements in the process of digestion, the most essentially nitrogenized part of it being turned into living structure, and partly changed into urea, so as to be at once dismissed from the system. The fats and the carbo-hydrates also contribute, and very largely, to the building up of the structures. But they only do so under the impulse, or stimulus, communicated to them by the nitrogenized substance. The energy, or power exerted in muscular action is very much greater than that which could be supplied from the nitrogenized constituents alone of the food. Such excess of power, therefore, must have been derived from the carbo-hydrates, or unnitrogenized constituents of the food, and a very considerable part of the carbonic acid, exhaled as waste from the lungs, must be furnished by the conversion of such nitrogenized structure as muscular fibre.

The leading characteristic of the proteid, or nitrogenized, ingredients of the food, probably is that they increase the activity of the living tissues, causing a rapid consumption both of themselves and of the non-nitrogenous food-substances associated with them. Therefore when a rapid transformation and renewal of the tissues, and an energetic accomplishment of work are required, an ample allowance of richly nitrogenized food, such as meat, contributes to the result that is sought; but, on the other hand, too liberal an allowance and unnecessary excess of this kind of food, and too rapid transmutation of the tissues serve to overcharge the excreting channels of the system with the unavailable nitrogenized waste, chiefly in the form of urea, and so tend to produce injurious derangements. Excess of urea cannot be stored away in the frame as excess of carbo-hydrates may. It must be at once removed entirely out of the way, and if, in consequence of some weakness or failure in the organs appointed to perform that task, the removal is not promptly and effectively performed, rheumatism, gout, or some allied derangement of the functions of the body, presents itself. The quantity of nitrogenized food that can be got rid of and the augmentation of vital energy that can be borne without injury to health, is entirely a question of individual capacity and soundness, and one which can only be determined experimentally in each individual case.

The fatty ingredients and carbo-hydrates of the food, on the other hand, do not stimulate and quicken structural transformation in the same dangerous way, although they are in the end capable of supporting the waste of muscular activity. Even when they are in large excess, they can be stored up and retained in the system with the utmost facility. In that case, instead of giving rise to bodies like urea, which require to be immediately removed out of the way, they constitute an available and valuable reserve which can be conveniently kept on hand, and drawn upon for serviceable work at any time of future need. They are either stored in the nooks and corners of the body as paddings of fat, or packed away into the store-chambers of the liver, as glycogen. The fat has weight for weight a larger amount of latent power condensed into its filmy vesicles, than an equal quantity of glycogen. But both are available for the performance of useful work, such as tends only to an increased exhalation of watery vapour and carbonic acid. A standard diet of duly apportioned proteids, carbo-hydrates, and fat may be so arranged, with skilful management, that it shall be adapted for the performance of any fair amount of work, without incurring secondary drawbacks and penalties. Such standard would only need to be slightly modified to meet the particular idiosyncrasies of individuals. In arranging the details of such a standard diet, the ready, or unready digestibility of the substances employed of course needs to be taken into account, as well as their mere force-producing capacities. There would be no real advantage in selecting a highly nourishing ingredient, if that ingredient were so tenaciously locked up as not to be readily and quickly got at and turned to account. For mere purposes of fattening, or storing up a latent reserve of force for future use, a due apportionment of nitrogenized and carbo-hydrate substances is required. For the support of energetic muscular labour, a more liberal supply of nitrogenized proteid food, under the precautions which have been alluded to, is allowable, because, as has been stated before, it, to so large an extent, promotes the serviceable appropriation of its non-nitrogenized associates. As a general rule, more than three-fourths of the muscular and nervous energy of the human body may be considered to be derived from the unnitrogenized carbo-hydrates of the food.

The inorganic and saline ingredients of both vegetable and animal food, such as phosphorus, sulphur, iron, salt, soda, potash, and also certain compounds that are designated extracts, do not contribute directly to the supply of active force. They are, nevertheless, essential to the healthy existence of the body. Any diet in which they are absent is altogether useless for the purpose of nutrition, as soon as any store of them which might chance to have lurked within the body has been exhausted. The service which they perform seems to be a kind of arrangement of the more abundant ingredients associated with them in structural composition, and a regulation of the way in which the various transformations are carried out. The superiority of fresh meat and vegetables to the various forms of preserved food appears to be chiefly due to the circumstance of their containing a good supply of these supplementary ingredients.

The muscles and nerve-structures are obviously the most important organs contained in the animal body. These have been very aptly and suggestively designated by the distinguished physiologist, Dr. M. Foster, the master-tissues to which all the rest minister.

Very nearly one-half of the human body is made up of its flesh or muscles. Quite one-quarter of the blood held in the body at any particular instant is contained within these muscles. The brain and nerves are of smaller bulk or mass than the muscles. But this inferiority in point of size is to some extent compensated for by the fact that, during the active exertion of these noblest of all the textures, the blood flows through their substance at an exceptionally rapid pace. The subordinate or servant-mechanisms of the body, such as the digesting and excreting organs, and some supplementary structures associated with them, are mainly engaged in dealing with the raw food, so as to fit it for the use of the master-tissues with the least possible labour and strain to themselves, and to accomplish as speedily and easily as may be the removal of the waste products which result from their action. The numerous intermediate changes of state, between the first introduction of food-substance into the blood and its final expulsion from the system, are yet but imperfectly understood. But they are all undoubtedly directed to the particular objects that have been already pointed out.

The body of the animal may thus be briefly and summarily spoken of as a complex and elaborately constructed machine, constructed for converting the latent, or so-called potential, energy stored up in material compounds by the plant, into active and effective energy, exhibiting itself as movement, sensation, nerve influence, and brain operations. The energy thus stored up by the plant for subsequent employment by the animal, is derived from the sun, the great cosmical and practically inexhaustible source of movement and power to the earth and to the other planetary spheres which are associated with it as a family of dependent worlds. It is caught in the vibrations of sunshine and softened daylight which are the immediate emanations from the sun, and it is worked up as the maintaining principle of the compounds that are elaborated by the vital chemistry of the plant. In its absorbed and latent state, it serves as the intrinsic bond that holds the elements of the plant-like structures in the form into which they have been cast; and when these structures are dissolved, by the oxidizing processes of animal life, it is disentangled from its structure-composing office, to be left free and turned to account in the animated mechanism. It is in this sense, therefore, that the plant prepares for animal life, and that the animal consumes the food with which it is furnished by the plant. The various changes of state, that are brought about in the materials of the animal body during the continuance of vitality, all serve to convert the sleeping energy, brought in by the food, into the active energy which is the distinguishing attribute of animal life. The oxidation of food into waste products under the fanning influence of the in-drawn breath; of nitrogenized food into urea and carbonic acid; of oil and fat into carbonic acid and water; and of starch and sugar into carbonic acid, is the process which is employed to break down the plant-constructed materials, and to disentangle from them the energy temporarily held in their substance. About one-seventh part of the energy which is thus disentangled and set free in the body of one adult human being is available for the purpose of external work, for moving from place to place, and for operating upon the objects of external nature, by means of jointed limbs. The remaining six-sevenths, and, therefore, by far the largest part, is consumed in the internal work of the mechanism which is required to keep its parts in due repair and in a serviceable state. When ample allowance has been made for this appropriation of power to the internal purposes of life, the one-seventh available for external work still represents a surprising amount of force. The external muscular work of a labouring man of average health and strength would suffice, if it were all applied in that way, to lift every working day about one million pounds one foot high. That, therefore, would be the work which could be extracted, by the agency of the living machine, from an allowance of four or five pounds of judiciously selected proteid, fat and carbo-hydrate food.* The same four or five pounds of dry food at the same time supplies internally appropriated power which, if also turned into the channel of external work, would suffice to lift another six millions of pounds one foot high.

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* It may not be uninteresting to compare with this the external work that can be got out of one pound of coal, by the agency of steam machinery. It amounts to a mechanical power that would suffice to lift a million and a half of pounds one foot high.

But the force, which is used for the internal work of the animated machine, all makes its appearance in another form before it is altogether lost to the mechanism. The heat of the body is virtually derived from the oxidation and destruction of its tissues. It is essentially the result of a slow burning up of the frame. Wherever a destructive change is set up in any fabric or constituent of the body, heat is evolved. But it is the destructive consumption of the muscles which is undoubtedly the chief source of warmth. When a muscle contracts, one part of the energy, that is set free by the consumption of its substance, is applied to the production of its movement and to the performance of the mechanical work which it accomplishes. But another, and, upon the whole, a considerably larger, part is directed to the evolution of heat. The proportion of the amounts that are applied to these different purposes varies to some extent with circumstances. The changes, which are brought about in the secreting glands and in the liver, are also attended by the development of heat. The brain, too, is a contingent source of supply. It is itself warmer than the arterial blood which flows into it for its sustenance. The circulating blood carries the heat from the various parts in which it is most energetically developed to all other parts of the frame which are less liberally supplied, and in that way serves to equalize the temperature; and it is finally radiated off into surrounding space from the cutaneous surface, communicated by direct contact to the air, and steamed away in the vapours that exhale from the lungs and skin. In warm-blooded animals, the production and loss are so balanced against each other, that a singularly steady temperature of the body is maintained. This varies in different animals to a limited degree. In the wolf it amounts to 95½ degrees of Fahrenheit; in the swallow it rises to 111 degrees; in the human body it stands, in ordinary health, just under 100 degrees for the deeply-seated parts, and at 98 degrees in parts where the cooling is just beginning to tell, like the hollow of the arm-pit, and the partially enclosed surface beneath the tongue. In cold-blooded animals, such as the frog, on the other hand, the temperature of the body does not ordinarily rise more than one of Fahrenheit's degrees above the temperature of the surrounding air. In such cases the destructive decomposition of the structures of the body is very sluggish, and the internal fires are kept burning very low. In the human body, a rise or fall of two degrees above or below the average invariably indicates that there is something amiss in the internal mechanism, and that some unusual and generally injurious influence is acting upon it.

Nearly seventy-eight per cent. of the heat of the body escapes in the end through the skin. The skin, therefore, is the chief cooling agent. It is the contrivance that is supplied for the regulation of the heat of the body. Such regulation is managed by varying the quantity of blood that circulates through the skin. The larger the quantity of blood that flows through the vessels of the skin, the greater is the amount of heat that passes away from it by contact-communication with the air, by free radiation into surrounding space, or by the exhalation of perspiration from its pores. Any influence which enlarges the capillary vessels of the skin, cools the body; and any influence which contracts the capillaries of the skin and enlarges those of the internal organs and structures, heats the body. When, strong, muscular exercise generates a large amount of internal heat, its loss by the lungs, and yet more effectively by the skin, is augmented in a similar degree, so that the average and proper state of the internal temperature is maintained. The glow of the skin experienced when brisk exercise is taken is one of the palpable signs of this process of compensation; the profuse perspiration produced by more energetic exertion is another still more obtrusive manifestation of its agency.

It has, however, been quite recently ascertained that there is a still further provision made for the regulation of the heat of the animal body. This was, in the first instance, discovered from the circumstance that more oxygen is found to be consumed by, and more carbonic acid exhaled from, a living animal when it is exposed to cold, than when it is in a warmer temperature. This certainly means that there is more consumption of the textures of the body during exposure to cold. The result seems to be due to the agency of a special nervous apparatus, which has the power of blowing up the internal fires and quickening the combustion when external temperature is low. It has been observed that this nervous apparatus may be paralyzed by the influence of the poison known as Urari, and that then the increased consumption of oxygen and augmented exhalation of carbonic acid are stopped, even during the prevalence of cold. The physiological explanation of the way in which the effect is brought about when the apparatus is in operation, is that, when cold acts upon the skin, it gives rise to a nervous impression there, which is forthwith transmitted to some central seat of nerve-action, and that this is then forwarded on, by special nerve fibrils provided for the purpose, to the muscles, stimulating them to increased activity in the generation of heat. When the nerves passing from the nerve centre are paralyzed, the stimulating intimation, of course, can no longer reach the muscles. It does not appear, however, that any contraction of the muscular fibres is connected with the performance of this heat-regulating action.

It is now generally held to be highly probable that there is some analogous provision by which the decomposition of muscle substance can be diminished and the heat of the body lowered, and that the excessive heat, experienced in fever, results from the paralysis of nerves that serve ordinarily to lower the internal temperature. The heat-producing decomposition of the muscular substance, in such circumstance, escapes from the control to which it is ordinarily subject, and runs riot. The well-known physiologist, Claude Bernard, believed there was some reason to conclude that the cooling nerves were supplied from the cerebro-spinal system, and that the thermogenic, or heat-stimulating nerves were offsets from the sympathetic nerve-system.

The temperature of the human body is maintained during health at somewhere between 97 degrees and 100·5 degrees of Fahrenheit. The rise of temperature from active exercise does not amount to two degrees of Fahrenheit, in consequence of the compensating operations with which it is connected. The temperature of the body is practically the same in Tropical and Arctic regions of the earth.

Death ensues from extreme cold, in consequence of a depression of activity in all the vital tissues, but especially in the nerve pulp. The same result also occurs from an elevation of from eleven to twelve and a half degrees of Fahrenheit above the ordinary standard of health, because it first makes the contractions of the heart irregular, and finally arrests them altogether. It most probably also extends its injurious influence to other parts of the living structure. The maintenance of a temperature of about 98 degrees is apparently arranged because that particular degree of warmth is the one most favourable to the changes of substance which have to be carried on in the body for the accomplishment of its vital actions. All the energy, developed in the internal actions of the frame, is finally discharged into external space as heat; but before it is dissipated in this way, it serves the all-important purpose of warming the blood and the textures of the body up to the point which is most suitable to the work they are engaged in performing. The blood itself does not appear to be materially concerned in the production of heat. It is the carrier of oxygen to the tissues, but not in itself a combustible. All the combustible food absorbed into the blood is transmuted into tissue before it is burned up into waste products, and only becomes waste through a destructive transformation of the tissue.

LECTURE X.

The Nature of Fermented Drink.

It is now easy, from a retrospective glance at the preceding lectures of this series, to understand why so very large an amount of water, two pounds to every pound weight of the other ingredients, is contained in the living animal body, and for what purpose in the arrangements of the vital economy so liberal an allowance is made.

That body, it will be remembered, has to be looked upon as built up on a delicate framework of branching tubes, or vessels, penetrating everywhere, permeating every shred, and filling every crevice of the structure, and having water flushing unintermittingly, under the recurring strokes of the heart, through the channels of these tubes, in order that the dissolved nourishment it conveys may be distributed to each nook and cranny of the frame, and that waste substance may be unceasingly and promptly washed away. Every organ is infiltrated and deluged, at all times, with this perpetually moving stream. It flows through flesh and brain, through heart and lungs, through skin and glands. But, as something like one hundred pounds of water are continuously employed in the general service of a living animal frame, and scarcely more than five pounds upon the average are added in the course of each twenty-four hours to the liquid flood, it follows that the same water has to pass again and again through all the interstitial channels of the various organs. A small quantity is drained off in various parts, as the movement hastens on, and an equivalent amount is added from time to time, to keep up the bulk of what would otherwise be a constantly wasting and gradually failing stream. It must, therefore, be distinctly kept in mind what the destiny is of the additions that are from time to time made, for the maintenance of the stream, in the form of drink. Every drop of the watery liquid so supplied flows over and over again, even many hundred times, through the very substance of the living organization, deluging and flushing its inmost recesses and pores, leaving as it does so, a small contribution of organizable matter here, and abstracting some equivalent quantity of worn-out material there. But, as a matter of fact, it must accomplish this journey, round and round, through the inner channels of the living structure before it can effect its own escape. The water, which is swallowed as drink, is passed in either through the veins of the stomach, or through the absorbing villi of some other part of the alimentary canal. It is then gathered into the large venous duct, conveyed through the liver, and then onward to the heart. From the heart it is propelled to the lungs, and back to the heart, and then to the brain, and muscles, to the stomach and skin, to the secreting glands and kidneys; and it is only after it has made this lengthened and intricate journey, and been subjected to this exacting ordeal, again and again, that it at last passes out drop by drop through either the exhaling pores of the skin, the breathing cavities of the lungs, or the capsules and excreting ducts of the kidneys. This fact, of its penetration everywhere to, and of its prolonged sojourn in, the most minute, retired, and delicate of the recesses of the living frame, must be thoroughly understood before any adequate conception can be formed of the influence and action of drink. Whatever it may be, once the drink has been received into the vestibule of the living organization—the cavity of the stomach—it is irrevocably on its way to the heart, lungs, muscles, and brain. Having been placed in the stomach as a thin liquid, it can only get to the appointed outlets of escape through the devious route of the innermost channels of the various vital parts. A very slight measure of reflection will make it apparent that this must of necessity be the case, since water is used as the great carrier of the denser ingredients of these structures. The water must go wherever the raw material has to be conveyed: wherever the work of construction has to be carried on. But that is in all parts of the organized frame; in every fibre and film of the most exquisitely elaborated of its textures. The water, or in other words, the drink, must therefore include in its subtle and searching progress, every fragment of the fabric that is the seat of vital endowment, and that is an integral part of the organization. The liquefied ingredients of the elaborated food-material being all more or less intimately mingled together in the circulating stream, abundant opportunity is afforded them to exert their chemical actions and reactions upon each other, and so to produce the successive compounds of increasing complexity which have been alluded to as marking the upward progress of annual organization, and the successive compounds of diminishing complexity which result from the degradation and decomposition of those compounds as their life-supporting, and force-producing operations are accomplished.

Some of the water, which is introduced into the bodies of animals, is closely and often even structurally associated with the more solid constituents of the food. But the great bulk of it is swallowed as drink. With all other animals, except man, this drink consists of water alone, or at least of water containing only such minute traces of soluble material as are accidentally present in rivers and streams, and in the springs that percolate the porous ground. But man, with the resources of artificial life at his command, makes use of various beverages which he is at some pains to prepare. In all of these, however, water is still the one essential ingredient that constitutes their usefulness as drink. All of them must, in the main, be composed of this bland and mobile liquid. The various substances, which add flavour and attractiveness to the drink are in all cases superfluous for the main object which it fulfils. For men, who confine themselves to water, as the lower animals do, continually enjoy the most vigorous health, if all other essentials of nourishment are duly supplied by the blood. Indeed, in the case of those who employ artificially-prepared beverages, such as beer, the first step taken with them, after they have been introduced into the stomach, is to separate them into two parts: the thin liquid water, and the thicker ingredients which have been mingled with it. The water is at once absorbed into the veins of the stomach, to mix with the blood and to carry out its proper office as the appointed agent of transport; whilst the thicker materials associated with it are left in the stomach to undergo digestion with the other dense food, and to be so prepared for introduction through the absorbing villi of the alimentary canal. All the glutinous substance or body of the beer is in reality food, rather than drink, and has to undergo true digestion in the stomach, after the water has been drawn away from it through the fine blood-vessels which cover the inner coat of that organ.

But the food-substance contained in beer is not in very large quantity. There is rarely more than three grains of it in each hundred grains of the liquid. The greater part of the three grains is composed of a kind of gum, which is dissolved out of the malt in the process of brewing. A portion of it is true sugar derived from the same source, and a small quantity is a nitrogen-containing, or proteid compound generated in the barley from which the beer is brewed, by the elaborating power of the plant. Of the nitrogen-containing extract there are generally something like forty grains in each pint of fairly strong beer. Of the sugar there are also about forty grains in each pint, and of the gum-like substance about three-quarters of an ounce. There is, therefore, a little less than an ounce of nourishing material in each pint of beer of good average quality.

But there is in beer, and indeed in all fermented beverages, something besides these nutritious ingredients, to which the most careful consideration needs to be given in any attempt to sketch the physiological influence of drink, since, as a matter of fact, it is the product in these beverages which has led to their being so generally and largely used by man in the place of pure water. When beer is about to be brewed, water, raised to a temperature of 180°, is poured upon crushed malt, which has been itself prepared by causing barley to germinate to a certain extent under the influence of warmth and moisture, and then stopping the germination by exposing the grain to dry heat in a kiln. In the process of malting, the insoluble starch, which had been packed away in the seed of the barley, is converted into soluble gum and sugar, and this gum and sugar are dissolved in the water, heated to 180°, when the bruised malt is immersed in it.

But the sweet-wort of the beer contains a much larger quantity of gum and sugar than can afterwards be found in the same quantity of beer, when the brewing is complete. The reason for this is that they are slowly and gradually converted into something else, in the next stage of the process, which is known as fermentation, and which is so called on account of the gentle boiling-like action which accompanies the change.* Bubbles of gas froth up in it, as bubbles of steam rush up through water when it is boiled. But in the case of the fermentation, the bubbles are not bubbles of steam. They are bubbles of carbonic acid gas, and that carbonic acid is extracted from the gum and sugar derived by malting from the starch. The sugar and gum, indeed, during the continuance of the fermentation, are in the act of being deprived of large portions of their solid ingredient carbon by the predacious powers of oxygen. The carbon is floated away by its agency into the air. The gum and sugar are thus being decarbonized by oxidation. This process of transmutation is in the first instance set going by mingling a small quantity of yeast with the still warm liquid.

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* The word fermentation is derived from the Latin term *fermento*, to puff up, or make spongy.

Yeast has the power of causing the molecules of the gum and sugar to begin to loosen themselves asunder, so that some of the liberated atoms of carbon can be seized by the oxygen. It is itself of the class of bodies known as zymogens,* or organized ferments, and consists of a mass of little living plant-vesicles, composed of a thin film of proteid, or albuminous membrane, which feed upon sugar, and, whilst doing so, turn one part of the sweet food into an enzyme, or formed ferment, which is then discharged into the liquid, to continue by its influence the sugar-decomposing action. It is in this way that yeast sets up fermentation in sweet-wort.

But, as the change goes on, and more and more of the carbon is abstracted from the gum and sugar, these substances themselves gradually disappear. They are destroyed as gum and sugar, and, so far as they are destroyed, the gumminess and sweetness of the liquid are lost. The carbon and oxygen escape, as has been described, as vapour.

But there still remains something of those original substances which does not escape, but lingers on in the liquid. This also is easily detected by certain sensible properties which the liquid acquires, and especially by the peculiarity of its taste. As it loses its sweetness, it becomes ardent, or burning, to the tongue. The residual part of the gum and the sugar is converted into what is very characteristically and appropriately designated "ardent spirit," or alcohol. The water with which it is mingled becomes indeed an actual "fire-water." The old chemists not altogether unnaturally conceived that the burning liquid, developed in sweet solutions by fermentation, was actually a mingling of fire with water.

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* See page 158.

The changes that take place when sugar, and gum which is, chemically, scarcely distinguishable from sugar, are converted into ardent spirit, are not at all difficult to understand. After the molecules of the sugar have been loosened asunder into their constituent elements, and portions of their carbon and hydrogen have been removed as vapour, the remaining carbon, hydrogen and oxygen are regrouped together, so that new smaller molecules are constituted, in each one of which there are bound up together two atoms of carbon, six of hydrogen and one atom of oxygen. This, then, becomes a molecule of alcohol, or ardent spirit, and assumes all the characters and properties by which the burning liquid is distinguished.

Symbol expressing the composition of each molecule of
alcohol, $H^6 C^2 O^1$.

The change, however, it will be remarked, is a degradation of the sugar, and in no sense a building up. The sugar is beginning to be destroyed by the abstraction from it of a portion of its ingredients. The spirit is a stage in downward decay. It is to the gum and sugar very much what urea is to the nitrogen-containing compounds from which it has been derived. It is those unnitrogenized products of elaboration advanced one step in the process of reduction and resolution into their primary elements.

Wine differs to some considerable extent from beer, in the circumstance that it contains less glutinous material. It also has its spirituous part impregnated and masked by even more agreeable flavours. Wine is, as every one knows, the produce of the grape. It was at one time conceived that there is only one species of wine-yielding grape. This, however, is certainly not the case. All wine-producing districts have their own kinds of vines, which have been improved from the wild state by cultivation and care, and by the natural influences of soil and climate. It has been observed, indeed, that the finest qualities of the most esteemed vineyards are lost if the vines are transplanted to less suitable positions. Twenty apparently distinct species of grape have been described as flourishing at the present time in the Valley of the Rhine.

The juice of the grape in its natural condition consists of a considerable quantity of sugar and tartaric acid dissolved in water, with very minute traces of more complex substances which have been elaborated with the sugar and acid by vegetable alchemy, and which confer the attractive attributes of colour, fragrance and flavour. During the progressive maturation of the fruit, the acid is in the first instance preponderant, and afterwards the sugar accumulates more and more, till the acid taste is overcome by the sweetness. The sugar of the grape is, however, of a peculiar kind. It is more prone than cane-sugar to take upon itself the chemical transformation which occurs in fermentation, being relatively more rich in hydrogen and oxygen, and less densely charged with carbon. It is also combined, in the juice of the ripe grape, with a small quantity of a yeast-like ferment which spontaneously starts the fermentative change. Each grape has its own little store mingled in with the sugar. Grape juice is thus transformed into wine of its own accord, without the addition, as in the case of beer, of an agent to cause the transmutation. In this sense, therefore, ardent spirit is altogether a natural product. When the juice of the fully-ripened grape has been pressed into must, and left standing in vats at a comparatively warm summer temperature, abandoned to its own uncontrolled impulses, a further removal of carbon takes place by the fermentation which ensues, and the new form of molecule, which is characteristic of alcohol, appears. In order that the juice may be converted into wine of good quality, by the natural process of fermentation, there must not be more than five parts of tartaric acid in each thousand parts of the liquid, and it must have two hundred parts in the thousand, or twenty per cent., of sugar. In fine seasons this proportion is easily secured. But in less propitious ones, the ripening is less perfect, and the juice contains more acid and less sugar. The wine then becomes of an inferior quality, unless the must is diluted with water to overcome the acid, and enriched with cane-sugar to provide for the proper spirituous strength. By the skilful exercise of art in this way good wine is often still produced.

When the ripened juice contains the due amount of twenty per cent. of sugar, the result of the fermentation is a wine possessing eleven per cent. of alcohol. This, however, is as high a proportion of spirit as can be produced by the natural fermentation of the juice, and it is, therefore, the standard maximum strength for natural wines. All alcohol, contained in wine in larger quantity than this, must have been produced by the process of distillation, and afterwards added as concentrated spirit to the wine. If an exceptionally sweet juice, containing more than twenty per cent. of sugar is fermented, as soon as eleven, or possibly twelve, per cent. of alcohol has been generated from the conversion of the sugar, no more is produced by fermentation, because the rest of the sugar is then preserved by the presence of the spirit. In such wines there is always a considerable amount of unconverted sweetness remaining after the fermentation has been carried as far as it can. The natural wines, which attain a strength of eleven per cent., scarcely ever retain more than a half per cent. of unconverted sugar.

It was at one time conceived that, in natural and unfortified wines, the alcohol existed in some state in which it was combined with other ingredients of the liquid, instead of being free as spirit. This notion arose from the fact that in such wines the spirit is not as immediately detected by the palate as it is in the strong, fortified wines. It was, however, subsequently proved that this is not the case, and that in natural wines the alcohol is simply masked by the presence of luscious flavours. In some notable experiments, spirit was distilled off from wine, and then again added to the lees as an unquestionably free spirit, and it was found that the reconstructed wine was quite undistinguishable from the original liquid. The ardent qualities of fortified wines are often due to the circumstance that the spirit is rendered more pungent, and more appreciable to the taste, in consequence of the generation of peculiar products out of the secondary ingredients, by the influence of the heat employed in distillation. There is, however, good ground for the belief that the strength of wines has been materially increased in the last few years, in consequence of the improved cultivation of the grape and the more skilful management of the vintage. Dr. Richardson has pointed out that some apparently trustworthy analyses of wines, made in the last century, gave only five per cent. of alcohol in Burgundy, and seven and a-half per cent. in Sherry. The strongest wine mentioned in the analysis, a kind of Malmsey, scarcely exceeded nine per cent. The strongest distilled spirits do not appear to have been used as ordinary beverages until within the last two or three centuries. Gin was not known, as a distinct name in any language, until about two centuries ago. Whiskey is modern form of the old word usquebaugh, which first appeared in printed books a century and a-half ago. Brandy, or Branntwein (burnt wine) is of still more recent introduction.

When alcohol, which has been generated in wine by the fermentation of grape-juice, is left to finish its career in a natural way, it very soon undergoes further transformation, and ceases to be alcohol. It absorbs fresh quantities of oxygen from the surrounding air, and splits up its molecules in order that they may be regrouped under this addition. In this way it is first changed into aldehyde, which is a kind of oxide of alcohol, and then into acetic acid. But in the case of the process in which wine is prepared to serve as a beverage, the liquid is put either into casks or bottles, in order to arrest midway the further progress of degradation and decay as soon as the full available complement of spirit has been made out of the sugar. Wine is enclosed in air-tight casks or bottles, when the spirituous fermentation is complete, simply that the air may not turn the spirit into vinegar.

A great variety of complex products are made in very minute quantities in wine during the fermentation of the must, but which, although in small quantity, still serve to confer the distinguishing characters of the almost innumerable different kinds. Some of these products are of the nature of essential oils, and contribute fragrance to the wine, as well as distinctive flavour. Some are highly elaborated extracts from the vegetable juice, soluble either in water or spirit; and some are acids differing in minor particulars from the tartaric acid which is always the most abundant ingredient of this class. Others are also generated in the most matured wines by a kind of chemical fusion of some of these acids with the spirit. The well-known penetrating odour of old wines is due to the presence of one of these, which is of almost universal occurrence, and which is designated œnanthic* ether, on account of the resemblance its odour bears to the fragrance of flowers. This subtle product, notwithstanding its obtrusive pungency, rarely amounts to one part in forty thousand parts of the wine. What is termed the aroma of wine is an altogether different thing from its flower-like fragrance, or "bouquet." The aroma is a true product of the elaboration of the plant, mainly of the character of an essential oil, is present in the juice before it is subjected to vinous fermentation, and is in its fullest perfection in the ripe grape The bouquet, on the other hand, is more generally due to the transformation of some albuminoid ingredient most abundant in the unripe fruit, and is itself developed during the process of fermentation. The bouquet in wine is a more subtle and delicate quality than the aroma, and very readily destroyed by exposure to the air. The large range of diversity, which is brought about by the agency of these variable ingredients, is strikingly illustrated by the fact that more than two thousand different kinds of wine are known in the English market.

Nutritious ingredients are in smaller quantities in wine than in beer. Sugar is indeed the only one amongst them which is ever present in any considerable quantity, and varies exceedingly in different samples. Some wines contain less than two grains of sugar in each bottle, and others have as much as five hundred grains. The natural, free acid of wine rarely amounts to more than from fifty to eighty grains in each bottle. When wine contains more than this, it generally indicates that it is turning sour from the conversion of its spirit into vinegar. The astringency, or roughness of wine is due to the presence of tannic acid, derived in all cases from the husk of the grape. All wines contain small quantities of saline ingredients, which are familiarly spoken of, when they are deposited from the liquid as tartar. The principal part of this consists of tartrate and phosphate of potash. The ash, in wine, sometimes amounts to from a half per cent. to one per cent. of its weight, and this ash is looked upon with respect and favour by physiologists, because it is an ingredient which may be turned to account in the constructive operations of living animals.

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* From the Greek words, *oinos*, wine, and *anthos*, a flower.

Distilled spirits are all primarily produced from the fermentation of sugary liquids. But their strength is concentrated by the act of distillation. The vapour of the spirit is driven off by heat, and is then condensed into the liquid state. Gin is procured by distillation from fermented grain mingled with juniper berries. The name is derived from "Genevre," the French word for juniper. Brandy is distilled from wine. Whiskey, like gin, is procured from fermented grain. Rum is the produce of the distillation of cane-sugar, or more exactly of the treacle which is associated with the crystallizable sugar in the juice of the cane. Whiskey, brandy and rum contain from twenty to seventy grains of unconverted sugar to the pint. The coarsest specimens of distilled spirit are apt to contain a kind of heavy alcohol, which is known as fusel oil, or amylic alcohol. This is an occasional product of the action of heat upon the complex principles employed in the process of distillation, and is very abundantly produced from fermented potatoes. It is sometimes prepared on purpose to be added to ardent spirit on account of the pear-like flavour which it communicates. It is more highly carbonized than ordinary alcohol,* and is on that account, more heavy, and less volatile. It is also more injurious and tenacious when taken into the blood. It very quickly and readily produces trembling, coldness and profound insensibility, and its hurtful effects are less speedily removed than are those of common alcohol.

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* The ordinary alcohol, procured from spirits of wine, is known to chemists as ethylic alcohol, in contradistinction to the heavy amylic alcohol, or fusel oil.

LECTURE XI.

The Physiological Influence of Alcohol.

THE ardent spirit, which is formed from sugar by the process of fermentation, can, by the ingenuity of the chemist, be separated from the liquids with which it is mingled when thus generated, for individual examination, and it is then found to be an ardent spirit in the most absolute sense of the word. In that state it looks to the eye as clear and limpid a liquid as water, but if a burning match be brought near to it, its difference from water immediately and very significantly appears, for it then bursts into a fiercely hot flame, and continues to blaze until it is entirely consumed. In that so-called consumption, it is, however, merely being passed on through the further stages of decomposition and decay. It is not destroyed, but simply resolved into a vapour that can no longer be detected by the eye. It is turned altogether into carbonic acid gas and aqueous vapour, considerable contributions of oxygen being drawn out from the surrounding air in order to enable the transformation to be accomplished. The flame is due to the circumstance of the very large relative proportion of hydrogen which remains in the spirit when the superfluity of the carbon has been removed by the slower combustion of fermentation. Hydrogen, it will be remembered, is a very inflammable gas, at all times ready to burst into flame when raised to a high temperature in the presence of air. It is the preponderant abundance of its hydrogen, then, that confers upon ardent spirit its inflammable proclivities.

When ardent spirit has been separated from fermented liquids in its purest state, it is the substance which is known as absolute alcohol. The epithet absolute is used simply to imply that it is the ardent spirit and nothing else. It is the spirit set free from the water with which it is associated in the process of its primary manufacture. Its presence in fermented liquids was, in the first instance, discovered by the Arabian chemists as long ago as the eleventh century, and from them it received the now familiar name "alcohol," which is merely two Arabic words, *al* and *kohol*, put together.* It appears to have been even at that remote period extracted by distillation, but not for purposes of drink. It was only used as a menstruum, or solvent, in some of the processes of alchemy.

Absolute alcohol is a quite clear, colourless, and very thin or light liquid, possessing a peculiar, penetrating smell, due to a considerable extent to the readiness with which its volatile vapour floats up into contact with the sensitive membranes of the nose, and an extremely burning taste perceived immediately when it is touched by the tongue. It is much lighter than water, bulk for bulk. The quantity, which would weigh one ounce, or 480 grains, if it were water, weighs only 384 grains as absolute spirit. A pint of pure water weighs twenty ounces. But a pint of absolute alcohol barely weighs sixteen ounces. Another notable distinction is that the absolute spirit cannot be frozen by any amount of cold to which it can be naturally exposed. Water, as is well known, is turned into solid ice at 32 degrees of Fahrenheit's thermometric scale; but absolute alcohol remains unfrozen and liquid at a temperature 200 degrees lower than that of freezing water. On the other hand, the absolute spirit boils at a temperature of 173 degrees, although water does not boil at similar atmospheric pressures until 212 degrees is reached. On account of this low boiling point, spirit can be at any time driven off by heat from any liquid in which it is present. The liquid has only to be kept for some time in an open vessel at a temperature a little in excess of 173 degrees, and all the alcohol steams away from it as vapour, leaving nearly the whole of the less volatile aqueous part behind.

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* The word *kohol* was, in the first instance, used by the Arabians for the name of a finely-levigated antimonial powder employed for dyeing the eyelids. It was afterwards extended to other powders which were in a very fine state of division, and ultimately to liquids conceived to be very much attenuated and refined. Ardent spirit, derived from fermentation, at a still later date appropriated the designation to itself. Rectified spirit of wine was first procured in the thirteenth century by Raymond Lully. Before that time, alcohol was only known in the diluted state in which it presents itself in ordinary, undistilled, fermented beverages.

There is yet another feature in which ardent spirit differs very materially from water. That, as has been seen, is an altogether indispensable ingredient of the living bodies of animals, and is present in them in the most copious abundance, serving to sustain all vital movements, and to quicken all vital operations. But absolute alcohol is a poison of the most terrific power. If, in this absolute state, it is poured into the stomach of a living animal, in anything beyond the most minute quantity, its potency as a poison immediately appears. It is as deadly, in such circumstances, as prussic acid, or any of the other fell poisons with which physiologists are acquainted. Two teaspoonfuls have been found sufficient to kill most dogs within a couple of hours. Rats have been deprived of life in forty minutes by twenty drops of rectified spirits of wine, and mice in ten minutes by five drops. Numerous instances are on record in which strong men have been almost instantaneously killed by drinking large quantities of strong spirits, such as those concentrated products of fermentation, whiskey and rum.

Another notable circumstance in regard to alcohol is that, although of such an antagonistic nature to bland water, it is, nevertheless, capable of mingling with it in any proportions. A single drop of alcohol will diffuse itself evenly through a pailful of water, so that some trace of its presence may be detected in every individual drop of the liquid. But a drop of water would mix in the same intimate way with a pailful of the ardent spirit. The water and the spirit have, indeed, such a strong disposition to mingle with each other, that they will make their way through the otherwise undiscoverable pores of seemingly water-tight membranes to do so. If a bladder, one-quarter full of alcohol, be immersed in a pail of water, and be left there for some time, the greater part of the spirit will make its way through the bladder to mix with the water. But the liquid in the bladder will, nevertheless, increase in bulk, until the bladder is stretched to its full capacity, because four times as much water will pass in, to mix with the spirit, as spirit will pass out. If the bladder of spirit be plunged into a running stream instead of into a pail, so that the water which comes into external contact with it is continually changed and renewed, in the end all the spirit will be drawn out of the bladder, to mix itself with the water.

This readiness of spirit and water to mingle is the reason why fermented beverages retain so large an extent of the spirit that is engendered in them by fermentation. In each beverage the spirit is mingled with the water, and is consequently diluted and reduced in its burning strength, according to the quantity of the aqueous liquid with which it is incorporated. In table beer there is something like one part of spirit and fifty parts of water mingled together. In ale and porter, four or five measures of spirit are contained in one hundred measures of water. In the strongest beer there are ten parts of spirit to each hundred parts of water. In wines of different classes, from ten measures of spirit to ninety measures of water, up to twenty-five measures of spirit to seventy-five measures of water, or one part of spirit to three parts of water. In ardent spirits, so called—that is, in brandy, rum, whiskey and gin—the proportion of the spirit to the water is considerably more. In the strongest brandies there is quite as much absolute alcohol as water; or, in other words, the absolute alcohol is diluted to just one-half its strength. Whiskey is somewhat stronger than brandy, and in some specimens of rum there are actually three parts of spirit to one part of water.

But whenever fermented beverages of the more dilute kinds, such as beer and light wine, are used as drink, and so introduced into the stomach, they are immediately placed in the same relative condition as the bladder of spirit immersed in a stream of running water. The stomach acts the part of the bladder, and holds the spirit, and the part of the running stream is played by the current of blood which is flowing so copiously through the capillary vessels of the walls of the organ. The spirit is consequently all drawn out of the stomach, precisely in the same way, to mingle itself with the liquid blood; and, once mingled with the blood, it flows on with it to saturate every part of the living structures. Henceforth it is no longer simply blood which is deluging all parts of the organs, but burning spirit and blood mingled together in some uncertain proportion, depending mainly upon the spirituous strength of the beverage. And whatever may have been the quantity of the spirit it originally contained, this all finds its way into the circulating stream of the blood.[*]

As, however, burning spirit is not a natural, or indeed necessary, ingredient in the blood, it is a matter of the utmost consequence to make out, as far as can be done, what the effect is of the introduction of the, in this sense, unnatural intruder when thus brought about. That it is not a necessary ingredient for any essential purpose, is incontrovertibly proved by the unquestionable fact that no drop of it is ever introduced into the bodies of the lower animals, such as horses, sheep and oxen, in the ordinary provisions of their lives; and that yet, in the bodies of those animals, precisely the same physiological actions have to be performed as those which are carried on in the bodies of men. There are the same flesh, nerve-substance, and glandular apparatus to be sustained; the same movements of circulation, and the same play of respiration and secretion. But over and above this, notwithstanding the very extensive use that is made of fermented drinks by human beings, there are innumerable instances of men who maintain the highest possible standard of vigorous health throughout their lives without at any time employing spirituous drink.

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[*] As a matter of fact, alcohol, diluted by water, is absorbed directly from the stomach by means of the venous capillaries of its inner coat, exactly in the same way as pure water itself.

That the spirit is not an indispensable and essential agent in the operations of the human organization is, therefore, a circumstance which may be accepted from the first, in any inquiry that is instituted, as a perfectly ascertained fact. It is a conclusion that is placed beyond the sphere of question, or doubt, by the indisputable force of experimental evidence.

And, again, there can be no doubt entertained as to what the influence of the intruder is, when in large quantity, although not in concentration enough to produce the immediate arrest of life by its poisonous energy. That too, unfortunately, is a circumstance which is referred to the actual test of experiment every day. The state of intoxication, produced in what is termed the intemperate use of spirituous drinks, is the answer which Nature herself furnishes to this branch of the inquiry, and it is a state in which the extreme penalty of death, from the ultimate accumulation of the effects of the poison, is only avoided, in too many instances, by the fortunate accident that the victim of the excess becomes unconscious and insensible before the deadly consummation is reached, and therefore incapable of putting the last touch to the destructive work. In all cases of intoxication, of whatever degree, the effects are due to the poison being carried with the streaming blood through the inmost penetralia of life. The spirit, with the blood, saturates every delicate structure in the frame. It penetrates the lungs, the liver, the kidneys, the skin and the flesh; above all things, it fastens upon the exquisitely delicate and blood-filled pulp of the nerve-structures and the brain, and in all of these interferes with the due and proper performance of the appointed work of those vital constituents of the organization.

One of the first signs of approaching intoxication, in men who drink fermented liquors to excess, is the well-known quickened stroke of the heart, accompanied by the flushing of the face, and the feeling of general excitement and vivacity. This is immediately caused by the enlargement of the minute arterial vessels of the frame, which is brought about by the direct action of the spirit upon the nerves that regulate the dimensions of these vessels. The fibrils, which in ordinary states diminish their size to the measure that is for the time most suitable to the accomplishment of the proper work on hand, are to some extent paralyzed by the deadening agent, even when it is present in this limited amount. The heart then quickens its stroke because, the channels of the small vessels being enlarged, there is less resistance to be overcome, and there being less resistance, like a steam locomotive which is relieved of some portion of opposing strain, it runs on with greater speed. The flushing of the face is caused by the greater quantity of red blood that is thrown through the dilated capillaries of the skin under the quickened action of the heart. But, as a matter of fact, all the structures of the frame, even to the soft pulp of the brain, are at this time flushed to just the same degree. In some cases, where men have died during the prevalence of incipient intoxication, the brain-pulp has been found to be crimsoned from its overcharge of blood. In consequence of this flushing of the brain, the thoughts, in the first instance, flow with augmented facility, and there is at the same time a general feeling of warmth in consequence of the corresponding quickening of the circulation that occurs in the skin. If, however, the supply of the spirit is continued, and more of the burning alcohol is drawn from the stomach into the blood, the thoughts soon become incoherent and purposeless. The ideas get rambling and confused, and cease to be obedient to voluntary direction and control; the conversation becomes inconsequential and senseless, thus vividly marking the disturbance which has been set up amidst the faculties of the mind. All these results are to be immediately ascribed to the injurious change that has been produced, by the spirituous poison in the brain-pulp which is the proper seat of intellectual manifestation and power. As, however, the mischief proceeds under still further accessions of the noxious spirit, the parts of the brain, which have charge of the formation of the vocal sounds and of the articulation of those sounds into speech, get involved, and the utterance of the words becomes thick and indistinct.

When the parts of the brain-pulp, which are concerned with the reception of the impressions of vision and hearing, are included in the disturbance, both sight and hearing are dulled and obscured, and distressing illusions are generated in the mind. When the soft pulp at the back of the brain, which has the office of directing the limbs in their complicated and co-ordinated movements, is impaired by the nerve-paralyzing influence, the muscles tremble and lose their power, the gait becomes uncertain and staggering, the balance of the movements is lost, and, in attempting to walk, the body is rolled from side to side. Next sleep supervenes—a sleep commonly so heavy and dead that the sleeper is in an absolutely insensible and unconscious state from which he is incapable of being aroused—because the grey pulp of the more central sensorial part of the brain is at length saturated with the deadening poison. At this stage the entire grey pulp of the brain fails to respond to the stimulus of the blood, and ceases to perform the structural transformations upon which its vital agency depends. In a general way it is this stage of insensible and unconscious sleep which intervenes to arrest the further progress of the mischief. As soon as the victim of the excess ceases to be able to augment the quantity of the poison that is streaming through the brain, the beneficent powers, which are implanted in the unconscious frame, begin spontaneously to clear the noxious intruder out of the system. The paralyzing load is gradually expelled from the blood, and the brain-pulp gradually resumes its usual work. But, if the quantity of the poison, which has already been introduced into the stomach, is in such large excess that the infiltration of the spirit into the blood must still be maintained, the grey pulp of the spinal cord and of the prolongation which connects it with the brain at length shares in the deadening paralysis, and the vital movements, of which it has the charge even during the insensibility of sleep, and which are quite indispensable to the maintenance of life,—such, for instance, as the play of the chest in breathing, and the beating of the heart,—then, in their turn, cease, and actual death ensues, either from suffocation, or from the arrest of the flow of blood. The end in such circumstances is poisoning in the most rigid acceptation of the word. But, in every stage of the sad progress there is poisoning, though in a less urgent, and in not alto hopeless a degree. It is on this account that the designation of the state has been so honestly and so aptly selected in reference to the great fact which has to be expressed. The word intoxication is merely a technical way of saying a poisoned state.*

The poison of alcohol tells more or less upon all the living structures of an animated frame; but it tells most speedily and heavily upon the pulp of the nerves and the brain, on account of the delicate complexity and high vitality of its composition. It fastens itself so immediately and so tenaciously upon the vesicular and force-originating portion of the brain, that this very commonly still yields manifest traces of its presence, when death has ensued many days after spirituous drink of any kind has been swallowed. The various effects, which have been described as accompanying the progress of intoxication, are all essentially due to the circumstance that the nerves and the brain are more quickly and more seriously affected by the paralyzing poison than other textures.

When the derangement, which ensues from the introduction of intoxicating alcohol into the streams of the circulating blood, has not been pushed beyond the first stage of quickened circulation, flushed face, and incoherency of thought, the portion of the spirit, which had attached itself to the pulp of the brain, is again gradually and slowly drawn back into the blood, and at last cleared away out of the circulation. Its ultimate destiny is the same with that of all other poisonous, or extraneous and intrusive, substances that are introduced into the blood in quantities not large enough to produce speedy destruction of the powers of life. They are gradually cleared away by the beneficently conservative energies of the frame, and expelled through the excreting organs and outlets. Very many of the most powerful medicines, indeed, produce their curative effects in this way. As foreign and undesirable intruders they rouse the expulsive activities of the system to rid the body of their presence; and, as they are expelled from the blood, they carry with them, through the quickened efforts of excretion, other noxious products which have been accumulating there, and deranging the balance of its adjustment.

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* The term is derived from the Greek word *toksikon*, which was the name for the poison in which arrow points were dipped to make them deadly. The Latin word *intoxicated* means virtually poisoned.

But when ardent spirit, which has been for some time lurking in the blood-streams in even moderate quantity, has been thus in the end cleared away out of the circulating liquid, the various organs, that have been roused to somewhat unnatural action to get rid of its intrusive presence, are very commonly left in a depressed and exhausted state, in consequence of the exceptional exertion which they have been called upon to make. This must be the case, because all quickened excitement of living structures is merely work taken out of them by anticipation. They, therefore, afterwards become languid in their action. The heart's stroke, which was strong and quick, becomes weak and slow. The secreting organs cease to separate the ordinary amount of waste products from the blood. The skin, which was warm and smooth, gets to be cold and dry. The mental faculties subside into lethargy and torpor, and at length more or less heavy sleep ensues, during the continuance of which the over-worked organs get reinvigorated and refreshed, so that in that way at last the more usual condition of the brain-pulp is restored. States of slight derangement, from the presence of alcohol in the blood, are thus in ordinary circumstances only followed by temporary disorder and discomfort, because the human body is naturally endowed with this beneficent faculty of righting itself, and of getting rid of extraneous ingredients that have found their way into the blood. The proce removal is, however, in every case a very slow and gradual one. The intruder clings with singular tenacity to some of the textures of the body, and especially to the brain. Its entire removal is a matter of days rather than of hours.

Thus far any inquiry into the action of fermented drink upon the living human frame, finds itself upon sure and well-established ground. There is no question as to the leading facts that have been brought under notice. There is no doubt, that all the essential operations of the living, human economy can be efficiently and vigorously performed without the co-operation of ardent spirit in any form; and there is no doubt that those operations are gravely and injuriously interfered with whenever the symptoms of intoxication, or alcoholic poisoning, are produced by the introduction of ardent spirit into the blood. The matter, however, by no means stands in the same clear and incontrovertible light, when the influence of the moderate and unintoxicating use of fermented liquors comes under inquiry. First and foremost, on the very threshold of the extended investigation, there appears the puzzling and perplexing uncertainty as to how it is that the intruder is ultimately removed from the blood. Assuming the case where two glasses of strong port wine have been introduced into the stomach, this implies that one ounce of absolute alcohol has to be imbibed into the streams of the circulating blood, and the work of expulsion immediately entered upon. Some small traces of the spirit soon appear as vaporous exhalations from the skin and lungs, and also in the secretion from the kidneys, and at one time it was too hastily assumed that the entire quantity of the spirit, which had been imbibed, passed slowly out in these ways. More careful observation, however, has since made it clear that this is by no means the case. Only a very small portion of the ounce of spirit can be accounted for by these exhalations and secretions. Yet, after a due interval of time, no trace of the spirit remains in the blood. This fact was put in a very conspicuous and striking light by a memorable experiment once made by the late Dr. Anstie, whose investigations into the agency of alcohol were most searching and exact. He gave a dog, weighing ten pounds, two thousand grains of alcohol, in divided doses, during ten days, and two hours after the final dose of ninety-five grains had been taken he killed the dog, and then subjected the entire mass of its body to distillation, to see how much of the two thousand grains still remained in its blood and structures. The utmost quantity of the spirit that he could recover by this distillation, amounted to twenty-three grains and a half. The perplexing difficulty, therefore, here presented itself of accounting for the disappearance of the other 1976 grains of alcohol. What could possibly have become of these? Certainly but a very minute part of them had exhaled through the kidneys, lungs and skin as unchanged spirit. The only alternative that remained, was the inference that the rest had been changed, in the laboratory of the living body, into something else which was no longer appreciable as spirit, and whose existence science was not yet competent to detect.

But the surprising result of this interesting experiment, and various other considerations of a similar tendency, open another stage of the complicated investigation that is of the highest practical moment. Can ardent spirit, after it has been taken into the system, by any possible means be turned to account as food? Can it be split into its constituent elements, and can these elements be then wholly, or in part, built in with the other ingredients of the structures? That some such use is made of the spirit would only be in accordance with the prevalent impression that there is strength of some kind, and support for the body, in fermented beverages; that men are more capable, w for muscular exertion, or for intellectual work, in consequence of the beer and wine which they consume.

That the inflammable compound, thus introduced into the blood, is not at once burned up by the reducing touch of the respiratory oxygen, and converted into carbonic acid and watery vapour, is obvious from the fact that no heat, at all in proportion to what in such circumstances would necessarily be generated, is really produced. The combustive destruction of alcohol out of the body, is attended by a very large development of heat. The flame of burning spirit is a very hot one. But the advanced stage of the saturation of the blood with alcohol is invariably attended with the production of cold in the body, instead of with the development of heat. The warmth, which is felt in the first stage of inebriation, is very transient, and is speedily succeeded by a low temperature and by persistent cold. And then, again, if the alcohol were burned into carbonic acid in the blood, as a matter of course an increased quantity of carbonic acid, which is the product of such burning, would be thrown out with the breath as a consequence of the operation. But such increase of carbonic acid, in the breath of persons under the influence of spirituous drink, certainly does not occur. The discharge of carbonic acid at such times is diminished rather than increased. The unavoidable conclusion, therefore, which is established by these well ascertained facts, is that the excess of the spirituous drink is not simply burned out of the blood. The only alternative that remains is the one which has already been alluded to—namely, that the spirit is converted into some other subtle product which has a less obtrusive and less marked individuality than the volatile and inflammable liquid; which passes through the outlets provided for the escape of waste and extraneous matter without detection; and which hitherto has eluded the scrutiny of the most skilled and careful observers.

LECTURE XII.

The Pathological Results of Intemperance.

THERE are certain considerations which seem to justify the view held by many well-qualified and conscientious investigators, that ardent spirit, after it has undergone decomposition and destruction as spirit, in the living human body, does in some instances act as a kind of nourishment, or food,—that in some qualified sense, it does give support to the vital strength of the organism. Thus it appears to be very fairly proved that, in some special instances, human beings have lived for surprisingly long intervals of time upon scarcely anything but a few morsels of bread, and a large quantity of spirit taken day after day. It is also quite certain that, in some depressing and exhausting forms of febrile disease, people are occasionally sustained through critical periods of the disorder by a very liberal allowance of brandy and wine.

There are thus two sides to this very perplexing question, and, as a consequence, there are intelligent and experienced observers who maintain that fermented drink is, in every case, either a useless or a noxious agent; whilst there are no less intelligent and experienced investigators who as strongly believe that it is a serviceable and nourishing auxiliary to the food, when employed in duly restricted and regulated quantities.

The common-sense conclusion from this conflict of opinion, which most readily suggests itself to unbiassed minds, assuredly is that as yet nothing appears to be satisfactorily known in reference to this particular department of vital physiology. No one can yet trace the transformations to which alcohol is subjected, when it is mingled with the complex and half-vitalized ingredients it encounters in the plasma of the blood, and in the laboratories of the organization. No one can yet say what becomes of the spirit when it ceases to be spirit, and no one can tell how it finally makes its way out of the blood.

But all that is known, of the half-chemical and half-vital processes carried on within the animated frame, points strongly to the high probability that, whatever the change may be, it must be one in which the appropriation of free oxygen is an essential condition. It must be an oxidation in some measure or form. Various compounds are known which are obviously the result of the further reduction and oxidation of alcohol.

The colourless liquid, recognized by the chemists as "aldehyde," and characterised by the emission of a peculiarly suffocating vapour, is one of these. The yet more familiar compound, acetic acid, or vinegar, is another of them. Aldehyde is, indeed, one stage forward in the degradation of alcoholic spirit into vinegar. Whenever wine is left fully exposed to the air, its spirit is speedily changed, first into aldehyde, and then into vinegar. If the supply of air is restricted within very narrow limits, and not freely supplied, aldehyde alone is produced. But the oxidation and destructive decomposition do not then proceed to the generation of vinegar. When wine becomes sour from exposure to the acidifying action of the air, it loses its spirituous strength in the exact proportion in which the acidity is developed. It is clearly the spirit, or alcohol, which is transformed into the acid by the acquisition of additional charges of oxygen. The aldehyde, which is formed by the oxidation of alcohol, has each of its molecules constituted by the grouping together of two atoms of carbon, four atoms of hydrogen, and one atom of oxygen.

Symbol expressing the chemical composition of a molecule of aldehyde, $C^2 H^4 O^1$.

The molecule of acetic acid contains two atoms of carbon, four atoms of hydrogen, and two atoms of oxygen.

Symbol expressing the chemical composition of a molecule of acetic acid, $C^2 H^4 O^2$.

But, if the free oxygen, which is furnished through the unceasing activity of the red corpuscles of the blood, is diverted from its proper work to the task of attacking intrusive alcohol and getting it reduced from its poisonous and burning state into a somewhat less actively injurious condition, whatever that may be, it is clear that the materials, which, under other circumstances, would have been removed by its oxidizing agency, must be to that extent left unchanged in the blood. Such materials, however, are waste substances which require to be cleared away. Consequently, as the work of the oxygen is diverted from them, they remain a load of contaminating refuse in the channels of the circulation. One obvious and very frequently-encountered instance, of this perturbing influence of alcoholic drink upon the balanced actions of the living economy, is the copious production of the red deposit in the secretion from the kidney, with those who make an over free use of fermented beverages. That deposit is insoluble uric, or lithic acid, superabundantly generated in the system because the nitrogenized waste, resulting from the wear and tear of nerve and brain, is not duly converted into soluble urea for easy removal in the natural way. The lithic acid, as has been already remarked, is urea arrested one stage in the process of downward degradation. It is urea which has been screened from the tooth of the oxygen by the intrusive alcohol which has intervened to appropriate that oxygen to itself.

Most people are aware that it is to this undue accumulation of lithic acid in the blood, and this insufficient and stinted production of the easily removed urea, which is the cause of gout, rheumatism, and the allied group of painful and too often obstinate and disastrous disorders. The beneficial influence of alcohol, when judiciously administered, in critical stages of wasting disorders, is in no way opposed to this view of its action. In such disorders, one prominent feature of the mischief is that the actual structures of the body are too rapidly and fiercely attacked by the consuming oxygen. The intervention of the spirit, in such circumstances, naturally arrests and diminishes the too ready consumption of the vital tissues themselves. Indeed the notion is rapidly gaining prevalence amongst intelligent physiologists, that this is one mode in which the moderate and habitual use of fermented beverages seems to act in a useful way. It moderates the waste of the structures of the body, and, in so doing, enables the real food to go farther than it would otherwise do in furnishing them support and repair.

But, while considering the action of fermented drinks from this point of view, it must be remembered that there is another side to even this aspect of the question. The appointed purpose of animal life is wear and tear, or rapid change. The most energetic of the structures of animal organization, such as muscle and brain, are those which have the highest capacity for undergoing destructive transformation. Their peculiar energies and power are furnished at that cost. The force developed is proportional to the fuel that is consumed. To stop the waste of such organs, therefore, is to lower the energies of life, to diminish the work of the highest character—that which is accomplished by muscle and brain. The relief of immediate strain comes in as a very beneficent aid, under circumstances in which, from some abnormal cause, it is desirable to husband the strength of defective or failing powers. But it can even then only be secured at the cost of a diminished exercise of the highest privileges of muscular and intellectual life. It is an expedient adopted upon the principle that a half vitality is better than no vitality at all. But it can in no sense be a desirable proceeding where there is an ample reserve of vigour in the frame, and where the organs of nutrition are in full and healthy play. The object to be then contemplated is an existence of full vitality, in which muscle and brain are most vigorously consumed and most energetically repaired—a state which certainly is not favoured by the "waste-arresting" agency of alcohol.

When all these considerations have been taken into account, there still remains the undoubted truth that a very large number of mankind habitually employ fermented beverages day by day, as a part of their ordinary diet, without shortening their lives and without experiencing any material amount of derangement or discomfort that can with certainty be ascribed to the habit, so long as the quantity that is consumed is resolutely restricted within moderate limits. But, in reference to this, there at once arises the delicate, and, in reality, very perplexing question, as to what moderation and temperance in this particular are; for this is a point on which well-qualified and largely-experienced authorities disagree. On the one hand, it is stated by intelligent and apparently unbiassed physicians that four glasses of strong port wine, or a bottle of claret, per day is a moderate allowance for most people; whilst others hold that a single glass, or a glass and a half of light wine, mingled with water, is an ample allowance for all healthy men. This discrepancy of opinion is, no doubt, in some measure, due to the circumstance that the standard of safety is different for different individuals. As a matter of fact, a quantity of spirit, that leaves no trace of derangement behind it with some people, is capable of producing really injurious results with others. This result in part depends upon the sensitiveness or bluntness of the nervous susceptibilities, but more upon the vigour and capacity of the excreting organs to accomplish effective work, upon the nature of the diet, and other particulars. Four glasses of strong port wine, as a daily allowance, is certainly more than can be safely disposed of by every one.

In considering the effect of the moderate use of beer and wine as a usual adjunct to the principal meals of the day, it is of some consequence that the various strengths of the different kinds of beverages shall be kept in mind. In strong port wine there is usually about 25 per cent. of absolute alcohol. This means that four glasses of such wine contain one glass, or something like two fluid ounces, of absolute spirit. In the case of four glasses of the wine being drunk, two ounces of spirit are therefore gradually churned up with the sixteen pints of blood. Two-thirds of a bottle of claret, hock, or champagne, a glass and a half of brandy, and five large tumblers of table beer, furnish approximately the same quantity of ardent spirit. There is some confusion and apparent discrepancy in the statements that are ordinarily made in regard to the alcoholic strength of wine and beer, because the percentage is, in some cases, given as referring to absolute alcohol, and sometimes in what is termed proof spirit; but these are, in reality, very different things. Rectified spirit is absolute alcohol diluted with 16 per cent. of water. It consists of eighty-four measures of absolute alcohol mingled with sixteen measures of water. Proof spirit is formed by mixing five pints of rectified spirit with three pints of water. It consists, therefore, of forty-nine measures of absolute alcohol and fifty-one measures of water, and is, therefore, approximately half water and half absolute spirit.

As there is with different people such varying susceptibility to the injurious effects of alcohol, there remains the unavoidable consequence that every individual must assume the responsibility of determining, as a matter of actual experience, where the boundary of what may be termed harmless indulgence falls. This, in reality, is a difficult task for most people to carry out with success; because, in the first place, very few are competent observers, on account of the ignorance in regard to the physiological operations of the body that so generally prevails; and, in the second place, because the judgment is warped by the pleasant sensations which the drinking of beer and wine almost certainly calls up. The mere force of habit, too, is an influence that needs to be guarded against. There is nothing more common than to hear men, who have been used to a liberal allowance of wine, say—when, for some reason, they have been induced to refrain altogether from it for a time—that they are certainly not so well in their abstinence as they were in their indulgence, simply because they are uncomfortable from the sense of forced restraint and from the restriction placed upon an enjoyable habit.

Perhaps one of the first things that requires to be done, in approaching toward a trustworthy solution of this difficulty by experimental means, is to escape from the thraldom of the influence of habit. If any one, who has become inured to the daily use of beer and wine, will carefully notice what occurs on refraining for a few days from the accustomed indulgence, he will find that there is at first a very distinct craving for the drink at the usual time; but that, under the resolute persistence in abstinence, this craving becomes less day by day, until in the end it ceases to be felt. If then wine be taken for three or four days, the craving will be recalled, and will only again disappear after several days of abstinence; or, in other words, after the continuity of the chain of habit has been broken.

But, apart from this thraldom of custom, there is the further circumstance to be noticed that with most people the habit is one which grows with indulgence. If, for a certain time, wine is taken until some agreeable feeling of pleasurable excitement is called up by its use, upon successive days, quite unconsciously, increased quantities of the seductive beverage will be desired. It is in this way that in most instances habits of intemperate indulgence are established, and this is perhaps the strongest argument that has yet been adduced in favour of their doctrines by the advocates of entire abstinence from fermented drinks. There may be, and no doubt are, some people who have self-command and force of will enough to keep rigidly within the limit that prudence and a reasonable conviction have established. But there are certainly very many more who are quite unequal to this task, and who yield to the insidious desire. The power of the seduction is assuredly expressed in the fact that there are no people on the earth who have not learned to create the means of intoxication in some form or other. But it is even more strikingly exhibited in the circumstance that Great Britain and Ireland spend more than one hundred and thirty millions of pounds sterling upon beer, spirits and wine every year. One hundred and thirty millions of pounds is a very large sum of money, and one which might be put in various ways to very excellent use. The seduction must certainly be very strong that can lead a rational community, not larger than that of the British Islands, to devote such an outlay to the indulgence; and this argument increases in weight when it is remembered that, apart from the most liberal allowance for differences of opinion and for debatable ground, there still remains so vast a proportion of this sum devoted to what is well known to be an intemperate and hurtful application.

It may also be strongly urged, as worthy of the consideration of those who habitually use alcoholic drinks in the most temperate way, how advisable it is that, even in that moderate course, there shall be occasional intervals of abstinence for a few days. This perhaps is the most satisfactory and sure guarantee of the avoidance of risk that can be adopted. It serves a doubly good purpose. It breaks the dangerous chain of habit which has been alluded to; but more than this, it prevents the unconscious accumulation of the tenacious spirit to a hurtful amount in the blood and nervous structures. As has been already stated, alcohol is only very slowly and gradually removed after it has been mingled with the blood. The circulating stream does not get a fair opportunity of clearing itself from the, at least, doubtful intruder unless the ingress is occasionally stopped. So long as fresh supplies are furnished, even in small quantity two or three times in the day, there is always the possible risk that the supply may be in excess of the removal, and that an undesirable and, at the same time, unintended accumulation is, in the end, brought about. It is very commonly observed that a certain amount of toleration of the poisonous influence of alcohol is established by use. Those, who employ large quantities of fermented drink every day, become gradually less prone to be affected with intoxication, and can consume augmenting amounts without showing signs of inebriation. This, however, is very easily understood. It is due to the circumstance that the delicate structure of the brain is already undergoing deteriorating change. The brain-pulp is affected by the alcohol in proportion to the delicacy and integrity of its organization. Whenever its structure has become condensed and dried by the agency of alcohol, whose natural tendency it is to deprive moist substances of some portion of their water, it is less sensitive to the disturbing effect. The alcohol then passes with the blood-stream on its way, instead of being at once arrested in the grey vesicles and attached to their pulpy substance. But the brain is to the same extent unfitted for its proper work. This is what is really meant by becoming seasoned to strong drink.

There is a somewhat common, but scarcely reasonable, belief that the stomach becomes in some similar way seasoned to the use of spirituous drink in any form. The teaching of physiology, however, is in no sense favourable to that view. As a matter of fact a very large part of the work of healthy digestion is performed by the agency of the ferment of the stomach known as pepsin, already described, which loosens out the dense albuminous ingredients of the food, and enables them to pass through the absorbing membranes of the alimentary canal, and to get in that way into the blood. This ferment appears to have the power to carry on its work in the presence of very dilute alcohol; but it certainly has not the power to do so when the alcohol is in any considerable strength. This is at once proved by an easily performed experiment. If albuminous substances, such as coagulated white of egg, or lean beef, be left for a few hours in a warm place soaking in a mixture of weak hydrochloric acid, artificially prepared pepsin, and water, those substances are finally dissolved exactly as they would have been if left for the same time in the stomach of a living animal. But if a considerable quantity of strong alcohol is poured into the mixture, no such solution takes place. The alcohol entirely suspends the fermenting power of the pepsin. Precisely the same result follows when a large quantity of strong wine is taken with an abundant meal. The pepsin for the time cannot do its work, and the gastric digestion is suspended, until the wine has been drawn out of the stomach by the absorbing vessels of its coats. The digestion is then carried on, but only in some halting and imperfect way. Perhaps one of the most frequent causes of the establishment of indigestion, with its concomitant miseries and woes, is the injudicious and immoderate use of strong wine. The digestive ferments in such cases are set to do their work in the presence of an agent which is notably an invincible antagonist to their digesting power. The sugar in strong wine is preserved from further change, as has been seen, as soon as the spirit of the wine amounts to twelve per cent. Even yeast itself is kept from further action and decay, when it is bottled up in a strong solution of spirit. This is the true explanation of the well-known fact that persons, who refrain from spirituous or vinous drink, so commonly acquire such vigorous appetites. The digestive ferments in their case are left to accomplish their work without the unnatural interference which alcohol exerts.

When fermented, and therefore alcohol-containing, drinks are used in great moderation, there can be no doubt that they may, in many instances, be so employed for considerable periods of time without leading to any discoverable derangement of the actions of the living economy, or of the structural integrity of the most delicate of its organs. This is proved by a very large experience. There are some people to whom even the smallest amount is injurious; but this is certainly the exception rather than the rule, and is due to some special delicacy or defect of organization. But how this immunity is to be interpreted and explained, after all that has been said relating to the poisonous influence of alcohol when it is introduced into the living structures, must, in the present state of physiological science, be so far held to be matter of doubt, as to leave fair ground to every one for the exercise of individual opinion. It is obvious that the result may be due either to the alcohol not exercising any injurious or objectionable effects upon the textures or the blood when in a very dilute state, as it is when not more than one or two teaspoonfuls are diffused through the two gallons of liquid contained in the blood-vessels of each individual frame; or it may, on the other hand, rather be a consequence of the singular power of the living economy to resist and escape from the injurious influence of extraneous and unnecessary agencies, and to free itself from irregularities, when these are not in too concentrated strength. There is nothing of weight in the mere fact that the agent is of a poisonous nature, because even food, in a certain sense, is a poison when taken in undue excess. Nothing is more certain than that the marvellously adjusted mechanism of the human organization is continually dealing with poisons in various ways, and escaping unhurt from the ordeal.

But whenever, in any individual case, the bounds of moderation, which are well within the scope of this recuperative power, are passed, the first influence brought into play seems to be due to the remarkable tendency which ardent spirit has to draw water to itself. This is one consequence of that ready miscibility of spirit with water, in any proportions, that has been already alluded to. Strong spirit will draw water to itself out of moist substances, and in doing so, as a matter of course, dries them to that extent by the act of appropriation. This is very strikingly indicated when the brain-pulp of a dead animal is immersed in strong spirit of wine. Such brain-pulp is so moist and soft, in its natural state, that it is torn by the slightest roughness of handling, and that it runs rapidly into decay. But after it has been plunged into spirit of wine, it speedily becomes firm and hard, and so durable that it can be preserved unchanged for years. This is entirely due to the moisture being drawn out of the pulp by the strong spirit. When a small quantity of very strong spirit is introduced into the stomach of a living animal, it actually dilutes itself by drawing water out of the tissues. But the albuminous membranes of the living body require, it must be remembered, to be kept in a moist condition for the due performance of their vital functions. If they were not in this moist state, they would not be freely permeable by the blood. No liquid secretion, or separation from the blood, would be possible if the vesicles and capillary vessels of the secreting organs were not maintained in that condition. No muscular exertion or brain action would be possible if the membranes and fibres of the muscles, and the films of the brain vesicles, were not kept in a similar moist state. All the organized compounds of the body, which are formed with the help of nitrogen and which are the most vitally active, are moulded into a soft jelly-like condition, that is technically distinguished as "colloidal."* The fibrin of the blood, the flesh and tendons of the muscles, the cartilages of the joints, the tissue of the skin, and the nerve films of the brain, are all examples of this colloidal matter, and the principal agent of their vital activity is their moisture. The water they contain favours the ready transformation of substance which is the physical provision for the liberation of serviceable force. But if these colloidal substances are kept continually deluged with alcohol, they are soon deprived of their moisture, and hardened into an impervious, leather-like state. This hardening and thickening of textures, which ought to be jelly-like and soft, is a change that is recognized by medical men under the distinctive epithet of "sclerosis."† It is produced by various conditions of derangement, but is of exceedingly frequent occurrence after the prolonged use of alcoholic drinks in very abundant quantity. It then affects all the most important organs of the frame. The lungs, liver, kidneys, heart, blood vessels, spinal cord, and brain, are all more or less involved in the change; but the spinal cord and brain are more prone than the rest to take upon themselves the destructive alteration, on account of the great abundance of water which their soft, moist pulp contains, and also because they are organs not naturally furnished with any form of secreting outlet. The spirit, having once made its way into their substance, can only be ultimately removed through being taken back into the blood vessels by a gradual reabsorption through the filmy walls of the capillary vessels. An undue softening of the spinal cord and brain is also very commonly found in inveterate drunkards. But this is in no way opposed to what has been said regarding the hardening of the delicate pulp, because it is, in reality, a still further destructive change which follows upon the hardening. The previous derangement in structure sets up a kind of inflammatory action, which in the end leads to softening, as a first step in the final process of molecular dissolution and disorganization. Intoxication, however, even in its transient and occasional form, is attended by some kind of structural derangement in the pulp of the spinal cord and brain. If the excess be of exceptional occurrence, the injury to the nerve pulp is gradually repaired. But if it be repeated again and again, the disorganization is at last rendered permanent by the repetition, and by the prolonged persistence of the poisonous influence. More serious perturbation of the function of the brain is then manifested. The irresistible propensity to renew the inebriation at frequently recurring intervals, which is known as "dypsomania," * is due to destructive change in the texture of the brain. Raving madness, which not uncommonly appears with it, is the effect of still further progress in the injury done to the substance of the same organ. The delirium tremens, or trembling delirium, that is so essential and marked a characteristic of inveterate habits of drunkenness, is another form of the same state, in which

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* From the Greek words *kolla*, glue, and *eidos*, resemblance, or like.

† From the Greek word *sclerosis*, hard.

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* "Thirst-madness." From the Greek words *dipsa*, thirst, and *mania*, madness.

the advancing disorganization is principally restricted to one particular part of the brain. The tremors which, in this form of delirium, recur in paroxysms, are not, however, ntermitting contractions of the muscular fibres, as at the first glance appears. They are really waves of inability to contract—waves of muscular paralysis passing intermittingly through the fibres of the flesh—the foreshadowings of a general paralysis of the muscular power, that is approaching with a halting step. Irremediable, hopeless paralysis and epileptic convulsions are the final results which attend upon such destruction of the organization of the brain. Whatever may be thought as to the ultimate effect of moderate indulgence in vinous and spirituous drinks in shortening the natural term of life, there can be no question as to the power of confirmed and uncontrollable intemperance to do so. It has been well ascertained that the fair expectation of life for a healthy and temperate man, who has already reached the age of twenty, is another forty-four years; but the expectation of life for a confirmed drunkard at the same age, is only fifteen years. The drunkard, as a general result, thus sacrifices something like twenty-nine years of valuable life, in addition to the very considerable number of days of that shortened period which he also destroys by mental incapacity or insensibility.

Quite irrespective of these well-known results of the grossest forms of confirmed drunkenness, there are various incidental derangements of the proper adjustments of healthy life familiar to medical practitioners, which can with tolerable certainty be ascribed to the more moderate, although habitual and continued, use of alcoholic drink. Authorities of the highest character and of the widest and largest experience have placed upon record their convictions that the habitual use of alcoholic beverages, even when restricted to an amount that falls far short of the quantity required to produce drunkenness, and that is conventionally held to be well within the limits of moderation, is the cause of a very large proportion of the most painful and dangerous diseases which are met with in the ordinary routine of medical practice.* One common result is the slow degradation of what should be the firm and compact texture of the fibres of the flesh into a kind of flabby fat, which is technically known as fatty degeneration. When this occurs, the powers of muscular effort and endurance fail, and, if the derangement involves the contractile fibres of the heart, its movements become liable in the end to be arrested in a moment by any sudden strain accidentally thrown upon them. The liver, next after the spinal cord and brain, is perhaps the organ that most frequently suffers in its integrity. Although it has not been found possible to prove that such is the case, it is probable in the highest degree that the conversion of the alcohol into some hitherto undetected compound, convenient for removal from the living body, is effected by the liver. But this, of course, can only be accomplished by an organ of such primary importance in the ordinary functions of life, at the cost of great incidental effort and strain. A darkened state of the blood has also been not unfrequently referred to the influence of the prolonged and unintermitted use of intoxicating quantities of vinous and spirituous drink, and that is obviously just what might reasonably be expected to be found where the oxygen, designed for the removal of the waste carbon of the structures, is diverted to the extraneous and incidental work of disposing of intrusive alcohol.

The several considerations which have been thus far passed in review, sufficiently indicate that the physiological action of drink is a subject deserving a more careful attention at the hands of the general community than it ordinarily receives. There is, perhaps, no branch of domestic habit and routine in which more momentous issues are at stake, and yet there certainly is none in which misconception and ignorance more commonly prevail. It is on this account that in the familiar statement of the case which has been attempted in these Lectures, a broad physiological mode of treatment has been pursued, and an appeal made to the reason, to intelligence, and to common sense, rather than to sentiment. It will not fail to be observed that some of the matters which have been touched upon, are held to have already assumed the definite aspect of ascertained truth and settled fact, whilst others still remain subjects of controversy and await further investigation. In reference to these unsettled and controverted portions of the inquiry, there is no alternative but that every individual must assume the responsibility of weighing for himself such arguments as can be advanced concerning them, and of forming a judgment upon the merits and probabilities of the case. But it can only be when the physiological conditions of such debatable matters are properly understood, that anything like a satisfactory conclusion will be formed, or that the benefit of the doubt under other circumstances will be secured. A very large number of those who acquire habits of undue and unsafe indulgence in the use of inebriating drink, most certainly do so in absolute ignorance of the danger that is incurred until this is brought home to their perceptions by the hard school of suffering, and after inveterate and ineradicable propensities have been established. No better protection against so untoward a result can be invoked than that which is comprised in a sound comprehension of the physiological actions involved.

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* See a letter addressed to the Archbishop of Canterbury, by Sir Henry Thompson. Printed in *The Times* of March 27, 1873; and again quoted in the Appendix, at page 220.

LECTURE XIII.

The Dietetic Value of Tea, Coffee, and Cocoa.

IN all cases of artificially prepared beverages, their power as drink unquestionably depends upon the water which they contain. It is the water that is drawn from them in the stomach, to maintain the free mobility, and transporting capacity of the blood, which are the essential parts in the service drink is intended to perform. The circumstance, that alcoholic spirit is taken from the stomach by the same ready route, when fermented beverages are used, is merely an accident due to the consistency of this liquid, to its free solvency in water, and to its habit of passing through films of thin membrane, in order to mingle with water. But for the primary objects for which the periodic introduction of liquid into the body is required, the water is better without any extraneous addition. It is better as a solvent, better as an agent of transport, better as a promoter of chemical transformation, and better as a scavenger and purifier. The entire series of artificial drinks are prepared and employed, not because they are more efficient for these all-essential and primary services, but because they produce some pleasant sensations over and above the office which the aqueous ingredient performs. In the case of some kinds of fermented beverage, such as strong beers and wines, and concentrated spirits, the superadded qualities are unmistakably antagonistic to the primary requirements of drink. They thicken the distributing stream, impede its free flow, and embarrass its transforming proclivities and energies. When this is the case, the fact is indicated by the natural feeling of thirst, the proper admonition that more water is needed, being transformed into an unnatural craving, that increases, instead of being satisfied and removed, with indulgence.

There are, however, some kinds of artificially prepared drinks almost universally employed at the present time, on account of the pleasant sensations that attend upon their use, which are not either fermented, or thickened to any material amount with extraneous substances, and to which therefore the objection just alluded to, applies with materially diminished force, if indeed it is pertinent at all. In such, certain soluble matters are extracted from vegetable elaborations by the aid of boiling water, and the infusions so prepared, are taken as soon as they are cool enough to be comfortably swallowed, and before any fermentative decomposition has been set going. There are three beverages of this class, familiarly known as tea, coffee, and cocoa, which have acquired a very large importance on account of their almost general adoption as beverages.

There is no ingredient in any of these beverages that is as treacherous and powerful for harm, as the ardent spirit, which is engendered in sweet liquids by fermentation; but there is, nevertheless, something in them of an altogether different character, which is capable of proving mischievous if they are intemperately or injudiciously employed. This possibly hurtful ingredient is present in a comparatively small quantity, but can be easily made to manifest itself by proper handling, as may, perhaps be most conveniently demonstrated in the case of tea. If a small quantity of tea be put into a watch-glass, and this be then placed for a few minutes upon the hot plate of a cooking range, and covered over by paper, it will be found that a light vapour soon rises, or sublimes, out of it, and is then condensed upon the paper in the form of white, needle-shaped crystals. This is a peculiar compound, fabricated in the first instance as a product of vegetable elaboration, in the leaves of the plant. It is a definite compound of the most perfect and finished individuality, and as pronounced in its specific characteristics, as either sugar or salt. It is a constant ingredient in the leaves of the tea plant, being never in any circumstance wanting in their composition, and is of a highly complex character so far as its constitution is concerned. Each primary molecule apparently requiring eighteen elementary atoms for its production, of which eight are carbon, five hydrogen, three oxygen, and two nitrogen. Like albumen and gluten, it, therefore, belongs to the nitrogen-containing group of vegetable productions, and in that particular, is strongly contrasted with alcohol, which is destitute of nitrogen. It is so important a result of vegetable activity that it has had a specific name contrived for it. It is known everywhere amongst chemists as "theine."*

Symbol expressing the chemical composition of a molecule of theine, $C^8H^5O^3N^2$.

The white crystalline ingredient, thus extracted from tea, is capable of exerting a very powerful influence upon the nerve-structure of living, human beings, when administered in a concentrated state. It first lessens the force of the heart's stroke, and diminishes the speed of the circulation of the blood. It then produces a feeling of gentle and pleasant excitement, very similar to that which is experienced shortly after taking nourishing food. If the dose administered has been large enough, it next causes a somewhat distressing wakefulness. Very large quantities may even be followed by convulsions, insensibility, and death. As a matter of fact, in its concentrated state, it is a potent compound of a similar character to the morphia which is extracted from the poppy, to the narcotine which is procured from tobacco, and to the quinine which is the medicinal ingredient in Peruvian bark.* Its chemical composition indeed very nearly resembles that of those substances. The full stimulant effect of theine is produced upon persons of delicate organization, by five grains. Any quantity beyond that is apt to cause wakefulness.

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* The word theine has been constructed from *Thea*, which is the Latin generic name for the tea plant.

The quantity of theine contained in tea in the state in which the dried leaf is introduced as a commercial product, varies considerably. In good, ordinary tea, there should be about 175 grains in each pound. A teaspoonful of tea weighs about seventy grains. In such a teaspoonful there should be from two to three grains of theine. Two teaspoonfuls of tea, in such circumstances, would furnish from four to six grains, which, it will be remembered, is the full stimulant dose. It will, therefore, be understood that people who drink many cups of strong tea in succession may easily get more of that active principle than is good for them. Thus far, the common impression that strong tea is apt to keep people awake if it be taken late in the evening, appears to be well founded.

It is not, however, on account of its containing this white crystalline substance, that tea is so generally used. The theine itself has a somewhat bitter and by no means pleasant taste; but there are other substances, of a much more agreeable flavour, associated with this product. The fragrance of the leaf is due to the presence of an essential oil, which also produces a sense of pleasant excitement when it is swallowed, and is destitute of any kind of poisonous or injurious influence. There is also in tea a not inconsiderable quantity of tannin, the astringent ingredient so largely developed in the bark used for tanning leather. Altogether, in each pound of good tea there are about five ounces of soluble substance, capable of being taken up into boiling water. Of these, a little more than two ounces is astringent tannin. Two ounces are different kinds of vegetable extracts mingled together; 175 grains are crystalline theine, and twenty-eight grains are essential oil. More than one-half of the pound of tea, or eight ounces, is coarse vegetable fibre that is insoluble in boiling water, and that remains behind as the mass which is left after the water has been poured away. If one hundred grains of good tea be boiled in water, until nothing more can be extracted, and the water then be poured off and carefully evaporated, there should remain behind about thirty-five grains of dry, solid residue. This is the soluble part which was extracted from the leaf by the boiling water, and which is, therefore, the active principle of the tea appropriated when it is used as a beverage. Any nutritious power which the tea may possess must, therefore, be contained in this soluble part.

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* It is said that in very hot countries, such as Penang, tea acquires actual narcotic powers.

The actual fact, as regards the good or bad influence of tea when used as an article of ordinary diet, is again a matter that falls to some extent within debatable ground. Its action, whatever this may be, is too occult and subtle to be traced in the existing state of physiological science with anything like certainty. There are some authorities who hold that it is a serviceable nourishment; and there are others who ascribe to it an injurious effect upon the nervous organization and upon the digestive processes, even when restricted to a very moderate quantity. It is, nevertheless, used at the present time, as an article of ordinary diet, by quite one-half of the human race, and it is obvious to the most careless inquirer that, at any rate, no injurious results at all commensurate with those which ensue from the excessive use of intoxicating drinks can ever be referred to its influence. The fact undoubtedly is, that it does not exert anything like the insidious seduction which is exercised by beer and wine. People do not habitually go on drinking more and more tea. Its use in injuriously large quantity is a rare exception, rather than a very general experience. The grave effects, which have been alluded to, are never produced from the mere dietetical use of tea, taken in the ordinary way. The only undesirable results that have been alleged against tea when so employed, have been a passing derangement of the functions of digestion, or temporary wakefulness and nervous distress, which, if really arising from the influence of tea, are quite sure to disappear on discontinuing its use.

If there be any nourishing power in tea, it must be very slight in amount. Such good service as this favourite beverage appears to render, must certainly be in some sense different from that which is derived from actual food. It seems to possess, when employed in the most judicious way, some subtle capacity for sustaining the nerve-substance in its work. Its exact mode of action in such circumstances is not thoroughly ascertained. But a large measure of actual experience tends to show that it is a refreshing restorative as well as an agreeable drink, and certainly not unwholesome when reasonably and judiciously employed. It certainly quickens the breathing, and gently stimulates the intellectual operations of the brain. The fact is somewhat noteworthy that tea is more commonly found to be an agreeable and highly appreciated beverage where fermented drinks are not used, than it is when they are habitually taken. Nevertheless, like the fermented drinks, it must be classed as an article of luxurious indulgence, rather than as a prime necessary of life.

The plant from which tea is derived is a native of Bengal, and apparently also of China, and belongs to the same natural order as the camellias of the gardens.* It is most probably indigenous along the entire range of mountains which runs from Upper Assam, through China, to the river Yang-tse-Kiang, and is now cultivated for its leaf in Hindostan, China, and Japan. The name "tea" is the English form of the Chinese word *tiä*, the designation given to the prepared leaf in the Province of Tukian.† The earliest mention of it occurs in an account given of the habits of the Chinese by an Arabian merchant in the year A.D. 850. The Jesuit missionaries who visited China and Japan in the first half of the sixteenth century, were familiar with it. It was first imported into England from Amsterdam, to which it had been conveyed from China by Dutch merchants, by Lords Arundel and Ossory in 1666, at a cost of sixty shillings the pound; but the East India Company had two years previously sent a present of it to the king. This Company began to procure it regularly from Bantam in 1669. Their first importation in that year consisted of one hundred pounds; within two centuries the importation into England had grown to nearly eighty millions of pounds.

At least forty distinct varieties of the tea plant are known. The leaf-buds and leaves are gathered by the hand at the instant of growth when they are in their fullest perfection. They are then dipped for half a minute in boiling water, and are afterwards stirred up in an iron pot heated over charcoal. The hot soft leaves are next thrown upon mats, and rolled between the palms of the hands. Under this treatment a quantity of yellowish green juice exudes. The rolling is repeated at intervals six or seven times. In the preparation of green tea less of this exudation is pressed out. The leaves lose two-thirds of their weight in the drying. The fragrance is entirely produced by the process of preparation. The dried leaf is never considered fit for use until it has been kept for twelve months.

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* Ternstromiaceæ.

† *Tsa* and *Tha*, are other Chinese forms of the word.

The most judicious method of using tea is to drink it in small quantities of fairly good strength. Some of the objectionable effect which has been attributed to tea may be rather ascribed to the large quantity of hot liquid habitually introduced into the stomach when it is injudiciously employed, rather than to the nerve-influence of the tea. Not more than one or two small cups should be taken at a time, and these should be regarded as a supplementary light refreshment, to be partaken of some little time after a more solid meal, and certainly not to be indulged in more than twice in the day. When drink in more copious abundance than this is required it should assuredly be taken in the form of pure, cold water, rather than as a hot infusion. The addition of milk and sugar to tea obviously communicates to it some nourishing capacity, which it does not possess without these adjuncts. There is one incidental service which tea is capable of being made to render, of such high importance that it deserves to be especially noticed. It is well known that the most dangerous properties of impure water are neutralized if the liquid is boiled before it is used as drink. Now tea cannot be made without boiling the water. Cold tea, therefore, is at all times an excellent form of drink where the salubrity of the ordinary water supply cannot be depended upon, and it forms a very palatable drink if flavoured with a little lime-juice and sugar. Cold tea was thus used by the troops in the recent campaign in Egypt with excellent effect.

There are some instances in which persons of delicate and sensitive organization are found to derive benefit from abstaining altogether from the use of tea; but a very much larger number employ it, under the restrictions and conditions which have been named, with unexceptionable results, and certainly without entailing any unpleasant or objectionable consequences.

Coffee, which by the mere influence of custom and accident, has become so intimately associated with tea, is the production of a quite different family of plants. It belongs to the same vegetable tribe as that which yields the Peruvian bark and ipecacuanha,* and the berry, instead of the leaf, is gathered for roasting; but, singularly enough, the berry of the coffee contains almost precisely the same ingredients as the leaf of the tea plant. A white crystalline substance, so closely analogous to theine that it can scarcely be chemically distinguished from it, is procured from the crushed berry by the same method of extraction. It is also rich in tannin; and a fragrant and very palatable essential oil is produced in the process of roasting. In each pound of roasted and ground coffee there are forty-two grains of the white crystalline and theine-like body,† two hundred and eighty grains of tannin, and a little more than two ounces of an albumen-like and nitrogen-containing extract. It has in it also five ounces of other more soluble vegetable extracts, and six ounces of insoluble vegetable fibre is left behind in the dregs after the ground coffee has been subjected to the action of boiling water. Nutritious substance is hence present in coffee in considerably larger abundance than it is in tea.

The coffee plant appears to have been originally a native of the highlands of Abyssinia, and to have been thence introduced into Arabia some time during the fifteenth century. It is now cultivated for commercial purposes in many tropical countries, and especially in Ceylon, Java, Brazil, and the West Indies. It is a shrub, or small tree, with shining evergreen leaves, and with very pretty clustering white flowers. The seed when fully matured, assumes the character of a bean, inclosed in a pulpy fruit. It is then principally composed of albumen. This bean is cleared of the outer pulp of the ripened fruit, and also of an external dry husk, and is then roasted over a fire in an iron pan, until the albumen is scorched into a crisp brown substance. During this process, a fragrant oil is produced under the operation of the heat, which then remains mingled in with the scorched albumen, and there becomes the immediate source of the agreeable flavour by which coffee is characterized, and for which it is so highly prized. Some part of the white crystalline caffeine, originally elaborated in the seed, is no doubt dissipated by the heat employed in the process of roasting.

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* Cinchonaceæ.

† Which however is called *caffeine*, when it has been procured from coffee.

Coffee must be freshly roasted and recently ground if it is to be taken at its best. The decoction is then more nourishing and less stimulant than tea; but it is more trying to the natural powers of digestion. The fragrant oil tends to retard the process to a certain extent, and strong coffee is therefore not always a wholesome drink for persons of delicate or deranged digestion. If used indiscreetly, it is apt to produce disorder in the elaborating and excreting processes of the liver. As a general rule, it does not suit people of full and plethoric habits, so well as those who are of a spare and languid temperament. Its influence upon the nervous organization is similar to that of tea. As with tea, it should be taken in moderate quantities, of fair strength, and should on no account be indulged in to unreasonable excess. Coffee seems to have found its way into general use at a somewhat earlier date than tea. The first coffee-house was opened in Paris in 1643, and coffee-houses were established in London soon after 1652. Twenty years ago, the yearly importation of coffee into Great Britain, had reached the very considerable amount of sixty millions of pounds, and very much larger quantities are at all times consumed in France, Germany, and the United States, than in tea-drinking England.

Cocoa and chocolate are produced from a plant which is a native of Central and South America, and which is now cultivated in Brazil, Guiana, and Trinidad. They are prepared from the seeds, of which there are several in each soft pulpy fruit. After the seeds have been removed from the pulp, they are dried, roasted, then freed from their husks, and afterwards broken into coarse fragments, in which condition they are known as cocoa nibs; these nibs contain about the same amount of an albumen-like, and therefore nutritious, substance as coffee; that is, about two ounces to the pound. But there is mixed with this a singularly large proportion of fixed oil, or, as it is termed, cocoa butter. One-half of the cocoa-nib is made up of this vegetable fat. In the preparation of what is termed "soluble cocoa," a considerable part of the butter is removed, and the remaining part of the nib is mixed up with starch, so that, when boiling water is poured on, the starch is converted into a kind of viscid gum, or mucilage, which then serves to suspend the finely ground and oily particles of the cocoa. Chocolate is cocoa, and starch or flour, made up into a sort of paste with sugar, vanilla, cinnamon, and occasionally with bitter almonds also.

The cocoa plant is a species of the genus Theobroma, and belongs to a distinct family of the vegetable kingdom, to either tea or coffee.* Yet, strange to say, it also elaborates a white crystalline substance, analogous both in chemical constitution and in physiological action to theine and caffeine.† Of this ingredient there are about 15 grains in each pound of the nibs. In the same quantity there is scarcely more than an ounce and a quarter of insoluble vegetable fibre. All the rest is material that is readily taken up by boiling water. The beverage is formed simply by infusing the ground powders, or pastes, in boiling water, and mixing the infusion so constituted, with sugar and milk. The pleasant taste, as in the case of coffee, is due to the essential oil and tannin dissolved in the water. Cocoa is apparently more nutritious and less stimulating than coffee or tea. It holds a somewhat intermediate place between drink and food, and requires more aid for its assimilation from the organs of digestion, than either tea or coffee do. On this account, it does not always suit persons of weakened, or deranged, digestive powers. A promising and palatable form of this food-adjunct, has been recently introduced into use, in which very nearly all the thick oil has been removed, and a nutritious extract from some kind of bean or pea really valuable as a nitrogen-containing food, substituted in its place.

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* Byttneriaceæ.

† The crystalline ingredient procured from cocoa is called "Theobromine."

LECTURE XIV.

Hünger and Thirst.

THE quantity of food that is required to support the operations of a living human body during a day has been approximately ascertained. In the case of prisons and houses for the poor, where unproductive people have to be maintained in fair average health at the public charge, and where, therefore, it is an object that a sufficiency of food, without wasteful excess, shall be provided, this has been made the subject of careful investigation. It has been in this way found that a man of adult age and average size requires about five ounces of meat, or other nitrogen-containing product equivalent to it, and twenty ounces of dry vegetable food, every day, to enable him to support the ordinary waste of vitality and to maintain the weight of his body. Ranke's experiences in this direction have been already spoken of. Sailors in active service are kept in full vigour and health upon a daily allowance of ten ounces of meat and twenty-six ounces of dry, unnitrogenized vegetable food.

But it is scarcely possible to adopt this plan of regulating the supply of food by measure and weight in ordinary life. The need for seeking fresh food is, therefore, in unimpaired health, left to be indicated by a natural craving, which is termed hunger. This calls into operation a very urgent desire for food when the body begins to want a renewed supply, and it ceases to exert any influence when the need has been duly met. In the state of simple nature this appetite serves as an efficient monitor, and its behests are loyally obeyed. People grow hungry when they require food, and cease to eat when the appeased appetite declares that they have had enough. But in the artificially created habits of civilized society, unfortunately the hints of this friendly monitor are not so carefully noted as they deserve to be, and foods of high flavours are indiscreetly indulged in, on account of the satisfaction which they afford to the luxuriously educated sense of taste, or, as is commonly said, to "tempt the appetite," but, as a matter of fact, with the actual result of superseding the appetite by a less trustworthy substitute, the artificially formed craving for the enjoyment of taste. When people use highly-seasoned and richly-flavoured foods, the natural guide is no longer of any avail, and more food is habitually consumed than the mere maintenance of vigorous health requires, with the ultimate result that the delicately constructed organs, designed for the removal of waste, have to be diverted to the task of getting rid of an excess which has no vital service to render. The healthy balance of the exquisitely adjusted mechanism is then destroyed, and the foundations are laid for further mischief, both by the overcharging of the blood with plastic material that can neither be worked up nor harmlessly laid by in store, and by the high pressure which is set up in the attempt to deal with the burdensome superfluity.

A still further penalty is apt to be incurred by the substitution of an artificial craving for the natural appetite for simple food. The condition of hunger is mainly due to some structural state that is periodically produced in the membranes of the stomach after a due period of repose from their vital labours, and that ceases to exist as soon as the secreting and digesting operations are resumed after due rest, in consequence of the introduction of new material to work upon. But when this new material is introduced in undesirable excess, the vital structures are oppressed by the unmanageable load, and are brought into a state of embarrassed action, which manifests itself by an uneasy sensation, or depraved craving, that is mistaken for hunger. This, indeed, is one of the most frequent accompaniments of the disordered state which is recognized as "indigestion," and which, as the name implies, is merely inability to perform the digestive work, brought on by the unnatural and unfair demands that are being made upon the powers of the organization. The disordered craving may generally be distinguished from the healthy appetite by the circumstance that it is increased, instead of diminished, by the taking of food. Hunger is appeased, but its depraved substitute is intensified, by a meal. As a matter of fact, an abundant meal of mixed food is five hours before it is finally passed on, in a duly pulped state, from the stomach, to be dealt with by the bile and pancreatic juice in the further part of the alimentary canal; and an additional interval of two hours is then also required for rest, before any fresh demand for active work can properly be made upon the organs. This, therefore, marks the period that should be allowed to intervene between meals, by persons in vigorous health and of unimpaired vital powers, who are abundantly fed. When meals are taken at more frequent intervals than this, it is of the utmost importance that they should consist of proportionally restricted quantity, and of easily assimilated material.

It is not possible to fix the quantity of drink that is required each day by any fixed estimate or rule analogous to the one which Professor Ranke has approximately established for food, on account of the great difference that there is in the amount that is necessary at different times. For this reason it is even more important in reference to it there shall be some natural indication competent to serve as a monitor and check; and this, indeed, is very efficiently supplied. Whenever the blood-plasma is getting too viscid and thick, a sense of thirst is produced, which at once causes an almost irresistible impulse to drink. This sensation is really due to the passage of the too viscid blood through the capillary vessels of the inner lining of the throat. It is this which causes the feeling of dryness there. Whenever a sufficiency of water has been introduced into the blood to restore its proper degree of fluency, the thirst is satiated and disappears; and whenever more water is introduced than is required for that purpose, the pores of the skin and the flood gates of the kidneys are opened to let off the excess.

But this system of natural regulation requires, it will be observed, that water itself shall be used for the quenching of thirst. If artificially prepared, and especially if fermented, liquids be employed as drink, instead of pure water, the nerves of taste are stimulated by the spirit, and by the various agreeable flavours associated with it, and an unnatural craving is in this way set up which is apt to be mistaken for thirst. In such circumstances, very much more drink is almost constantly taken than the mere preservation of the right degree of mobility in the blood requires, and the excess has to be got rid of, too often at the cost of undue pressure and strain upon the excreting organs.

But too much water in the blood almost certainly means also a larger quantity than can be conveniently accommodated in the channels of the circulation. The chief bulk of the blood is made up of water, and therefore any undue addition of water to the liquid involves an undue augmentation of its quantity until the pressure gets relieved
the flood gates. But when the blood is in undue
derangements of a particular kind are very
produced. If the skin, with its too copious

blood is suddenly chilled by exposure to cold wind or rain, its vessels contract under the influence of the cold, and drive the chief portion of their liquid load in upon the unchilled, internal parts of the body. This leads to a double excess there. Already there was too much blood in all parts of the frame, and when the portions of the excess, which ought to fall to the share of the skin, are driven in from the skin to the internal parts, the excess becomes proportionally larger there. The blood gets "heaped up" in the internal capillaries. This produces the very common form of derangement in the vital structures which is technically known as "congestion."* The word merely means a "heaping up." The disorders of such very frequent occurrence, which are known as "colds," are all of this class. They are congestions of some internal membranes of the frame, in which superabundance of blood is heaped up in consequence of so much having been driven in from the skin by the chilling effects of external cold. In colds affecting the head, congestion affects principally the capillary blood-vessels of the delicate membranes lining the eyelids and the nose. In sore throats the congestion extends to the mucous membranes lining the throat, and in chest-colds, attended with embarrassed breathing and cough, the congestion attacks the lining membranes of the air-tubes and air-cells of the lungs.

The actual condition of matters which occurs in these congestions, can be seen by direct inspection in the case of the transparent web connecting the toes of the frog. If this be carefully adjusted before the glasses of a powerful microscope, and if its surface be touched with a brush that has been dipped in an infusion of cayenne pepper, the small branching vessels will be observed to contract upon the blood which is streaming through them. If the same part of the web is touched a few times in succession, the contraction of the small vessels disappears, and a very distinct enlargement, or dilatation takes its place. The delicate vessels lose their contracting power under the rough treatment to which they have been subjected. They become flaccid and exhausted, as if weakened by the previous strain. But the arriving blood is then " heaped up " in the dilated space, and lingers there instead of flowing nimbly on; this is really congestion set up in that part of the web. In congestion of any vital structure, there is always an increased quantity and a diminished movement of the blood. In sore throats and colds of whatever kind, the mucous membranes of the affected part have exactly the same thing happening in their minute vessels that may be observed in the transparent web of the frog's foot when this is irritated by cayenne pepper. Inflammation is a still further stage of obstructive derangement of the movement of the blood through the capillaries into which, in unfavourable circumstances, congestion may be pushed. What then takes place can also be observed in the web of the frog's foot. There is absolute stagnation of the flow of the blood in one part, and a greatly quickened flow through the other capillaries around, and through the arterial trunks which supply those vessels. The object of curative treatment, in all cases of congestion, is promptly to relieve the " heaped up " state of the capillary vessels, and to prevent the further stage of inflammatory action from being brought about.

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* The word is derived from the Latin term *congero*, which signifies to heap up.

If, at the instant of the first establishment of congestion, a sufficient quantity of the too abundant blood could be withdrawn from the deranged parts, this would effectually put a stop to the heaping up and overloading of the vessels. But, unfortunately, the removal of any material quantity of the blood is a removal of vital strength, and on this account is never now attempted, excepting in cases of special urgency, and after grave consideration. The bulk of the blood may, however, happily be diminished, without any removal of the more vital and supporting portions of its plasma. The bulk, as has been seen, is mainly made up of water. If, therefore, the fresh accessions of water are, for a time, withheld, the bulk gradually lessens itself. One of the most certain means of quickly relieving the congestive derangements of colds is, therefore, to refrain altogether from drink until some feeling of thirst is established, and then to continue so far to limit the drink as to keep up the thirst for three or four days, or until all the congestive discomfort has been removed. Most persons can refrain from drink for two, and some even for three, days, without any other serious effect than the production of a feeling of listlessness and languor, accompanied by a small, easily quickened pulse and a dry state of the mouth, which ultimately settles into thirst. But these symptoms all disappear when drinking is resumed, and leave no ill effect behind. When, however, abstinence from drink is adopted for the speedy cure of congestive derangements, the utmost resolution must be exerted not to return to copious drinking as soon as severe thirst is felt. If this be done, the derangement certainly returns in full force, as if with a bound. The blood must be kept within the limit of thirst; or, in other words, thirst, to a just tolerable extent, must be maintained for certainly some time. The way in which this usually effective method of curing a cold acts is both intelligible and obvious. When the bulk of the circulating blood is diminished a little below the usual standard of natural requirement, the needs of the healthy operations of life become so imperative that the main force of the stream is expended upon them, and no excess is left to keep up the extraordinary engorgements and congestions elsewhere. The small capillary vessels are then quickly relieved of their burthen, and after a few hours' or days' relief, as the case may be, recover from their relaxed condition, and resume their ordinary calibre and firmness, or, as this is termed, tone. This expedient of refraining from drink is, indeed, so effective in its action, that it may be advantageously employed as a preventive as well as a cure. Persons who are unavoidably compelled to expose themselves unduly to inclement weather, may generally protect themselves from liability to colds by simply placing themselves beforehand upon a restricted allowance of drink. The old and time-honoured method of curing colds by keeping in warm rooms, or in bed, and by taking large quantities of demulcent drinks, is also intelligible, and in no way contradictory to the explanation here given of the influence of the dry plan of cure. It acts by drawing the blood away from the internal parts, where it has been congestively heaped up, back to the skin, and by finally removing a considerable amount of its aqueous portion through the cutaneous pores, as perspiration. In order, however, that this old method may be certainly efficacious, it is indispensable it shall be so managed that more liquid is thrown out through the pores of the skin than is taken in as drink. The warmth and perspiration must be steadily maintained, when once established, until the capillary vessels of the internal parts have been allowed to free themselves from their relaxation and to recover their tone. This plan also unfortunately has the concomitant disadvantage and inconvenience that it leaves the person who has been subject to it very liable to the repetition of the congestive action on the occurrence of a chill. Confinement to the house, or protection in some way from external cold, therefore, needs to be adopted for some time after the first recovery. With the alternative plan of treatment, on the other hand, exposure to external cold may in most instances be safely braved as soon as thirst is once fairly established, and the recovery will proceed during the usual prosecution of the business of life. It is, on this account, a very valuable resource when intelligently apprehended and practised.

The chief difficulty that has to be overcome in the application of this powerful method of preventing or curing congestive colds, is that it requires an almost Spartan resolution to refrain from drink until the cure is accomplished. It is a notable circumstance that most people are so held under the thraldom of habit as to be unable to refrain from drinking even for a few hours. They unconsciously confound the force of habit with the natural craving. As a matter of fact, severe thirst is rarely produced in most persons who have been drinking freely with less than from thirty six to forty-eight hours of abstinence. Yet there are few indeed who attempt the method of cure for the first time who will not insist that they are terribly thirsty before the first day is out. This really means, however, that they are terribly weary of restraint from the mere customary indulgence of drinking. Few, nevertheless, who are able to acquire a rational control over their sensations and propensities in this particular, will fail to avail themselves of the help, when they have once experienced the relief from more serious discomfort and more inconvenient consequences which the temporary exertion of self-denial secures; and this more especially when they have once realized also the intensified enjoyment which the act of drinking, even in the most limited amount, confers during the continuance of the curative ordeal.

Too free an indulgence in drinks, even of the most harmless character, is certainly very much more commonly met with than anything approaching to restriction. The most usual result of excess in this particular is a sense of uncomfortable fulness, palpitation, irregular action of the heart, and oppressed breathing; and these effects are generally continued until free perspiration breaks out, or until some congestive derangement is established. The more nutritious constituents of the plasma, and even the red corpuscles of the blood, may be unduly washed away by the too copious use of even water; such as is sometimes made by delicate persons who have acquired an irrational faith in water-drinking, and pushed their belief in its efficacy to an injudicious and unwarrantable extreme. In such cases the mischief is almost always indicated by the pallid and bloodless condition of the skin, and by a general sense of lassitude and weakness. On the other hand, the copious use of water as a drink may be made to render the most valuable service in cases where the blood is overloaded with the unassimilated ingredients of a too generous and too abundant diet, and where the excreting organs are vigorous and healthy enough to bear the increased demand upon their activity which the proceeding unavoidably establishes. Too copious indulgence in aqueous drink needs to be most carefully guarded against wherever there is defective power, or incipient organic derangement of either kidney, lungs, or heart, as it necessarily throws some increase of strain upon those vitally important organs.

APPENDIX.

Extract from Sir Henry Thompson's Letter alluded to at page 196 :—

"I have long had the conviction that there is no greater cause of evil, moral and physical, in this country than the use of alcoholic beverages. I do not mean by this that extreme indulgence which produces drunkenness. The habitual use of fermented liquors to an extent far short of what is necessary to produce that condition, and such as is quite common in all ranks of society, injures the body and diminishes the mental power to an extent which I think few people are aware of. Such, at all events, is the result of observation during more than twenty years of professional life devoted to Hospital practice, and to private practice in every rank above it. Thus I have no hesitation in attributing a very large proportion of some of the most painful and dangerous maladies which come under my notice, as well as those which every medical man has to treat, to the ordinary and daily use of fermented drink taken in the quantity which is conventionally deemed moderate. Whatever may be said in regard to its evil influence on the mental and moral faculties, as to the fact above stated, I feel that I have a right to speak with authority; and I do so solely because it appears to me a duty, especially at this moment, not to be silent on a matter of such extreme importance. I know full well how unpalateable is such truth, and how such a declaration brings me into painful conflict, I had almost said, with the national sentiments and the time-honoured and prescriptive usages of our race. . . . . If I ventured one step further, it would be to express a belief that there is no single habit in this country which so much tends to deteriorate the greatness of the race, and so much disqualifies it for endurance in that competition which in the nature of things must exist, and in which struggle the prize of superiority must fall to the best and to the strongest."

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